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ABSTRACT

Designed to provide an international cross-section of data on science and mathematics education, this document describes the educational systems of countries that developed innovative approaches to science education. The science-centered systems of Japan, People's Republic of China, East Germany, West Germany, and the Soviet Union are featured in this symposia series publication of the American Association for the Advancement of Science. A review is provided of each country's educational objectives, philosophy, practices, curricula, teacher quality, and teacher education programs. Concerns associated with the disciplinary approach to secondary instruction, the polytechnicalization of general education, and the role of education in technological development are addressed. The basic differences between U.S. policies and practices and those of Japan, West Germany, East Germany, China, and the Soviet Union are explained and the lessons derived from this study are discussed. Nine specific recommendations are offered in areas dealing with the school, teacher preparation, and the federal government. (ML)

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Science Education in Global Perspective

Lessons from Five Countries

Edited by Margrete Siebert Klein and F. James Rutherford

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About the Book

The decline in the quality of American public school instruction, particularly in science and mathematics, is a well-documented subject of concern for our nation. This book examines the educational systems in Japan, the People's Republic of China, East and West Germany, and the Soviet Union, countries that have developed particularly innovative approaches to science education. By providing an international cross-section of data, this volume serves as a comparative document of value to American educators, lawmakers, and the involved public.

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WILLIAM D. CAREY
Executive Officer
American Association for
the Advancement of Science

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Dr. Klein wishes to acknowledge the supportive role of the American Association for the Advancement of Science in making this book possible. Its publication is due largely to the encouragement and support of the outstanding staff of AAAS. In the early stages, the contributions of Gary Todd, whose participation was always characterized by skill, cooperation, and good cheer, and Joellen Fritsche, whose support was a key factor underlying the initiation of this book, need to be recognized. Production of a final manuscript would not have been possible without the diligent efforts of AAAS publication office staff members Kathryn Wolff, David Savold, Susan O'Connell, and particularly, Valerie Montenegro.

Preface

American education today is at a crossroads. Numerous studies bear witness to a general decline in the quality of public school instruction, especially in science and mathematics. We are warned of a national crisis with serious implications for the future vigor and health of American intellectual and industrial society. The present situation has attracted the attention of serious students of American education, members of the American scientific community, and concerned lawmakers across the political spectrum. We can be certain that, at least in the near term, a full range of quick-fix and superficial approaches to the problem will be proffered in the educational marketplace. Such proposals, if accepted, will give the impression of response and action. But they will fail if they do not redress basic problems in both the structure and substance of American science education. Only the development of durable programs and educational strategies will, over the long term, lead to the revitalization of American public instruction. My optimism about the resourcefulness of American society leads me to believe that we will follow the latter course, and the present volume is presented in the positive spirit of participation in that task.

In rethinking American science and mathematics education, it is essential to approach the task from a global perspective. Our national interest requires us to examine in detail the various models and approaches to science education undertaken by those who are or will be our major economic and ideological competitors. The aim of this book is to provide a comparative document that will assist American educators, lawmakers, and the concerned public in developing this international perspective. The authors describe the educational systems of countries that have developed particularly innovative approaches to science education. The book is initiatory in the sense that it is the first to provide an international cross-section of data on this topic, but it is by no means definitive. Further study will be required to ascertain the applicability of particular approaches to the American educational system.

Of particular interest, however, is the polytechnical approach to general education in Communist countries. That approach provides instruction in many scientific and technical subjects throughout the elementary and secondary school years. It is explored here with

full recognition of the gap between the advanced level of scientific and technical knowledge being acquired by a comparatively large segment of the youth in these countries and the inability of these same regimes to translate such knowledge into the economic well-being of citizens. This gap, which implies a failure in socioeconomic theory, in no way detracts from the achievements of Communist educational theorists. In Communist countries, research in education is treated seriously, as is education policy, which is designed to achieve maximum efficiency in the interests of the state. An examination of Communist successes in this area should not be dismissed on ideological grounds alone, since it is in our own best interest to be aware of both their successes and failures. On the other hand, the technological and industrial advances made by Japan and the Federal Republic of Germany are too well-known to need further comment here. Their school systems also provide models of effective science education, and they too underscore the importance of a cross-cultural examination of educational practices.

This volume grew out of a symposium entitled "A Challenge for American Education: Scientific Literacy in Japan, the Germanies, and the Soviet Union." This symposium, which I co-chaired with Dr. Joseph I. Lipson, then director of the Division for Science Education Development and Research at the National Science Foundation, was presented at the Annual Meeting of the American Association for the Advancement of Science held in Washington, D.C., in January 1982. Other symposium participants included Professor Izaak Wirszup, Dr. Kay Michael Troost, and Dr. Vivian Edmiston Todd. Although at the time Professor Wirszup's work on mathematics education in the Soviet Union and my own work on science education in the Communist countries as represented by the German Democratic Republic had already come to national attention, the symposium was the first presentation at a general scientific meeting of this research on the approaches to science education in Japan and the Federal Republic of Germany. In a very real sense the authors of the present volume are among the pioneers in developing an understanding of the deficiencies in American science and mathematics education through comparisons with other countries.

Since our symposium presentations, Dr. Troost has returned to Japan and I have traveled to both East and West Germany to undertake further research. Both Dr. Troost's chapter on Japan and my own chapter on the two Germanies have been updated to include our most recent data. Professor Wirszup's paper has also been fully revised to cover information on Soviet science teaching to 1984.

A few words concerning the heroism of Vivian Edmiston Todd are in order. During the early planning stage of the symposium, the vitality and enthusiasm of Dr. Todd were an inspiration to both Dr. Lipson and me. We were unaware, however, that at that time she was terminally ill. Despite the tragedy of her personal circumstances, Dr. Todd's commitment to the revitalization of American science education was such that she felt compelled to participate in the symposium. With the assistance of her husband Leonard, Dr. Todd outlined her involvement with and perspectives on science education

in Japan. Two weeks after the symposium, she passed away at her home in Long Beach, California. Her perseverance and commitment, however, are a lasting tribute to her outstanding career. As curriculum specialist for the Allied military government in Japan, Dr. Todd established, through the reconstituted Japanese Ministry of Science, Education, and Culture, a universal science education program that begins in first grade and continues uninterrupted through the universities and technical institutes. In Japan, she is known as the "grandmother" of Japanese science education, and much of what Japan is today in terms of its technological capability can be attributed to her pioneering efforts.

In addition to the contributions of the symposium participants, this book is enhanced by the work of several other experts. F. James Rutherford, Chief Education Officer at AAAS, joined me in the task of editing the volume. Dr. Rutherford also contributed a final chapter, in which he summarizes the lessons to be learned and makes recommendations for American science education. Dr. Kathleen Fisher, associate professor of biological sciences education at the University of California, Davis, graciously contributed her insights into the sociology of American science education to the introductory chapter, which she coauthored with Dr. Lipson. We are pleased to include a new chapter by Professor Paul DeHart Hurd, an eminent science educator with first-hand experience in the People's Republic of China. He describes how the Chinese are attempting to develop an educational system that will optimize the scientific and mathematical talents of their young people. We include this chapter because it provides another example of an educational system that stresses training in science from the earliest school years and because it provides a unique view of the educational plans of a nation encompassing one quarter of the world's people. Finally, we are grateful to Dr. Charles McFadden, a Canadian-based science educator with first-hand experience in the Soviet Union, for permission to include his chapter describing aspects of Soviet science education.

The present work highlights three major areas of concern for American educators. First, it will become apparent to readers of this book that the preferred approach to science and mathematics instruction in the countries described is the teaching of an array of disciplines, over a period of years. This is in contrast to current practice in American public secondary schools where students are taught one science for one academic year, then move to another discipline the following year, and in public elementary schools, where science may not be taught at all.

Second, policymakers understand in each of the countries described that young people cannot participate effectively in modern, technological society unless they have a broad understanding of technology and its application in industry. The implementation of this attitude has resulted in the polytechnicalization of general education, particularly in the Communist countries. As a consequence, instruction in mathematics and the sciences has become more closely linked to the requirements of modern industrial society than it has in the United States.

Third, as more countries achieve industrialization, the United States is facing greater and greater challenges in the marketplace. Policymakers in countries studied in this volume understand the key role played by education in their nation's technological development. Our effective utilization of their educational innovations will help us remain technologically competitive and may, in fact, ultimately contribute to the survival of Western democratic traditions.

Margrete Siebert Klein
Washington, D.C.

Introduction: Science Education in Other Countries— Issues and Questions

Japan, China, the two Germanies, and Russia command our attention as major nations on the world stage. They are of great interest both culturally and economically. Our national history has been intimately involved with them in both war and peace; their history and myths have captured a place in our national imagination; and their strengths as competitors challenge us daily. China, Russia, and East Germany consider themselves to be Marxist nations, and this ideology influences almost every aspect of their national and daily life. Japan and West Germany are now democracies and capitalist economies. In World War II, Japan was conquered and occupied by the United States, and we shall see in Chapter 1 that our occupation staff influenced the Japanese educational system in important ways. While the United States also played a major role in the conquest and post-war occupation of West Germany, the structure of the school system in the Federal Republic was not substantially affected and has continued an earlier tradition of tripartite education.

The People's Republic of China (PRC) has also gone through major political upheavals since the beginning of this century, and this has affected its educational system in major ways. Today, with one-fourth of the world's population, China is attempting to provide a basic education in science and technology for a whole population in order to join the ranks of major industrialized nations by the end of this century -- just as those nations are trying to achieve an even higher level of technology based on ever greater scientific and engineering knowledge. A common thread that unites all five of these nations is the major emphasis that each is placing on science and technology education for all students during the nine, ten, or twelve years the students are required to spend in school.

As the impact of science and technology on events and decisions continues to grow, U.S. science education policies and practices are in serious need of restructuring. The authors and editors of this book believe that an examination of the educational systems of other nations will help us understand our own. This volume, prepared by authors with first-hand experience in the countries they write about, describes certain aspects of science education in each of these five nations that should help us explore alternative

approaches. While the information presented here cannot supply answers to all of the pressing educational problems being debated today, it does offer perspectives on the central place of required science and mathematics in the educational programs of these other nations, and on the means they employ to promote high-quality science education for all their citizens.

As with any other highly complex system, an examination of the way nations educate their children in science requires that we selectively focus on the issues and dimensions we judge to be important. Thus, the list of issues examined here is neither definitive nor exhaustive. However, we hope readers will accept the discussion as the beginning of a national conversation which will continue and in which they will become active participants. To this end, we offer a number of comments and questions which will, we hope, serve to keep the conversation ongoing.

The principal benefits of looking at other approaches to science education are, first, to see how science education systems might be organized, and second, to see some of the relative merits and liabilities of particular systems. The science education practices of any country can be thought of as a series of natural (uncontrolled) experiments. Extreme caution is required in interpreting them, however, because of the differences among societies and the vast number of variables, many of them unknown, that may influence the outcome of any social system. Cultural heritage, customs, and values are only some of the factors which interact to produce a particular educational system and make it more or less effective in achieving that country's stated educational goals. The social and political milieu, natural resources, and economic conditions also have substantial impacts on educational systems. Stated another way, a particular philosophy or practice is not easily transported from one country to another. When such an adoption is attempted, as in the grafting of many American ideas into the Japanese educational system after World War II, an intricate pattern of adjustments occurs as the new ideas interact with previous practices and traditions. Thus, the outcome of a particular intervention may be substantially different in different settings, and it may have unexpected positive or negative side effects.

The questions which led to this book, and the lessons to be learned from it, are general ones. We can observe the practices of other countries and some aspects of their educational achievements. We can ask what the apparent risks and benefits are. We can look for hints of relationships between science education and other social phenomena. Finally, a review of the practices of other countries can provide a checklist of ideas and possible actions to help us understand the strengths and overcome the weaknesses of our own science education system.

The next few pages offer the reader a framework for viewing the subsequent chapters, and, we hope, identifying specific situations, interesting questions, and salient comparisons applicable to the United States.

POSSIBILITIES FOR CHANGE

Long-term trends are often easy to see, but the factors responsible for the trends are usually difficult to identify. Yet if a society is going to exert a deliberate influence on its own future, it must understand causal relationships. In the United States, for example, standardized achievement test scores in mathematics and science have declined steadily over a twenty-year period. Educators have struggled to determine the causes of this trend and find ways to reverse it. Their limited success leads us to ask, How much control can we as a society exert over the outcomes of our educational processes? What are the steps to achieving significant, nationwide changes?

In China, for example, as Chapter 2 makes clear, the educational system has responded rapidly to changes in the political climate. The impressive gains made after the 1949 Communist victory were seriously compromised during the decade of the Cultural Revolution (1966-1976). Now the educational system seems to be responding again with amazing rapidity to changes in other sectors of the society. Are the Chinese successfully implementing a massive new push to provide science and technology education for all citizens? Would any of China's methods for bringing about an increase in the level of science learning be useful, appropriate, or even possible, in a democratic society? The other nations we examine here have also recently made significant, if not so drastic, changes in their educational systems. In what follows, we look at important choices each has made.

SCIENCE LITERACY VERSUS A SCIENTIFIC ELITE

The United States has long depended, with considerable success, upon a small educated elite to provide scientific and technological progress for the nation. So long as science attracts its share of the most talented young people, it has been widely assumed, the rest of the population can afford to be relatively illiterate scientifically. Do these other countries accept this model? We will see that, while our five countries strike somewhat different balances between educating a scientific elite and giving all citizens a fairly rigorous education in science and mathematics, each is attempting to do both. Communist China, in fact, first concentrated on developing an elite, suffered the destruction of that group, then reversed its policies, and now is trying to bring its entire population up to a new level of scientific knowledge while restoring the elite.

The USSR has also reversed its stance on the importance of a scientifically literate society. Until recently, the Russians concentrated on early identification of special talents and intensive "hothouse" cultivation of an elite in each technical field. But in the last fifteen years, and particularly since about 1975, the USSR has launched an ambitious program to provide a challenging scientific and technological education to every citizen.

Chapters 4 and 5 report on an impressive educational effort, although in the absence of Soviet participation in international achievement tests in science or mathematics, it is difficult to assess their progress.

We should take note of the general problem of separating rhetoric from reality, dogma from fact. Investigators depend greatly on government reports, and a single investigator cannot sample enough of a nation's schools to determine whether official reports on methods and achievement are accurate. When government goals generate a conflict between reality and official expectations, distortions may occur. There is also the ever-present problem of loss of subtleties when translating from one language to another, and from one educational system to another, especially in the absence of measurements on a common standard of performance. However, the superior performance of the Japanese student body as a whole on international examinations offers reliable evidence of that nation's success in achieving its stated goal of giving all its students (95+ percent) an intensive science education. In addition, Japan trains a strong scientific elite at its major universities.

East Germany (GDR) and West Germany (FRG) offer an interesting comparison between systems that share a common language and heritage but have made different decisions about single versus multitrack educational systems. The tripartite educational system of West Germany allocates students into a low-middle-elite hierarchical system with selection heavily influenced by family background. One unfortunate result, as Chapter 3 points out, is that the school system tends to "program" students for unequal job opportunities as early as the fourth grade. In contrast, East Germany mandates a uniform and demanding science curriculum for all students through a 10-year general polytechnical program, and gives special support to interested and talented science students through extracurricular classes and academic Olympiaden.

So at least three countries in our sample -- USSR, GDR, Japan -- appear to provide a fairly rigorous scientific and technological education to more than 90 percent of their youngsters while continuing to find and educate students of high talent to carry on the scientific and technological activities of the future. These examples suggest that a scientific elite does not have to be produced at the expense of the rest of the populace, nor does the elite have to be sacrificed in order to achieve mass education. But the real question is, Why have these nations, each with a lower GNP than the United States, invested so much effort in the science education of a whole nation? They say that they see a relationship between science education and the economic prosperity and well-being of their nations. If that is so, how should we tackle this issue in the United States, given the following conditions:

- Our amazing diversity;
- The variable quality, quantity, and availability of science education at present;

- A system of elective courses that allows almost any student to choose to learn only a small fraction of what all students are required to learn in these other countries.

These and many other factors make the task of improving U.S. science education formidable.

CENTRALIZATION VERSUS DECENTRALIZATION

The American educational system is more decentralized than that of almost any other developed or developing country. The PRC and the USSR are comparable to the United States in geographic size and diversity of population (although both are larger, more diverse, and multilingual as well), but their educational systems are heavily centralized. East and West Germany provide a contrast in centralization and decentralization. East Germany relies on centralized authority and strives for uniformity, while West Germany is highly decentralized and prides itself on its diversity. In Japan, the post-war educational system owes much of its character to the highly centralized authority of the Mombushō -- the Ministry of Education, Science, and Culture -- in educational affairs. Uniformity of quality, equality of opportunity, and economies of scale are some of the benefits of centralization claimed by those who support centralization. Flexibility and creativity are often cited as benefits of decentralization. What is the optimal balance?

UNIFYING PHILOSOPHY

Scientific knowledge is reproducible, public knowledge. It represents a particular state-of-the-art view of reality which is shared in common by scientifically knowledgeable people. Whatever the passions and biases of any individual scientist, the methods of scientific investigation generally will eliminate gross errors within a reasonable period of time. Unifying principles are established that best represent current understanding of reality and predict future events in many novel situations. And, as some predictions fail, principles are modified and/or new ones discovered.

A repeated theme in the descriptions of Communist countries is the harmony between science and the dialectical materialism of Marx, Lenin, Engels, and Mao Zedong. Thus, an education in science is considered an enlightenment that cannot be at odds with Communist theory. Students are to understand concepts (rather than memorize facts) and apply scientific theories and principles to every aspect of society. In this context, science teaching and learning are valued endeavors, strongly supported by the central government. In addition, science education produces a technologically skilled workforce essential for the economic well-being of the nation. Thus, in Communist countries, there is a consensus that a high-quality science education is essential for every individual, and that the state has a responsibility to make that education available to all citizens.

Does rigorous mass learning require a stable ideology that values and rewards such learning? Stated another way, Do

ideological conflicts and contradictory messages from the society erode the will and capacity for widespread intellectual achievement? The perceived value of education in the United States, for example, has declined at the same time that higher degrees have proliferated and job opportunities for many "overqualified" degree holders have declined. Many factors seem to reduce motivation for teaching and learning science in this country, yet the sales of popular scientific magazines are increasing steadily, and computers are already found in many homes. What are the principal sources of motivation for the study of science in this country, and do they carry anything equivalent to the force of a powerful political ideology whose leaders also control who gets what jobs?

While admiring their successes, we should not overlook contradictions in the approach of Communist governments to science. Given the expressed belief in dialectics and scientific enlightenment, how and why did the Soviet Union promote Lysenko's theories long after they had been disproven in the West? What led to the suppression of the theory of relativity in the USSR? On the other hand, how do we explain the power of Creationism in the United States, or the strong resistance to the metric system? Political, religious, and social ideologies are often incompatible, or at least inconsistent, and can have simultaneously positive and negative effects on scientific learning and scientific progress. Can we in this country develop science curricula to avoid these conflicts?

TEAMWORK, SOCIAL SUPPORT, AND INDIVIDUAL COMPETITION

We read a great deal these days about Japanese industry and the role of teamwork in its success. Japanese firms are known for a management style that involves a sharing of both risk and responsibility among all employees. To what extent does this style evolve from, or penetrate into, the educational system?

Japanese classrooms aim to promote teamwork, group effort, and social support of the individual student. Competition for grades is minimized in the early years. Students are encouraged to help one another in preparing for the critical external examinations. A warm, supportive learning environment is said to be provided both at home and in school, a claim largely confirmed by American observers. On the other hand, Japanese children face a battery of external examinations that are critical in determining each child's future. They even must compete for the relatively few openings in prestigious kindergartens!

It is difficult to separate the effects of teamwork in the classroom, on the one hand, from effects of external examinations on the other. From a psychological point of view, both may be helpful (to a degree) for maximizing learning. Since learning means taking risks and making mistakes, a warm, supportive environment at the point of learning seems desirable. At the same time, since most of us are stimulated by external pressure, a decisive consequence (such as an external examination score) that is a function of our own learning effort ought to be a powerful incentive. What is the

optimal balance? The extent and form of exam-generated stress and the discouragement associated with being "tested out of" many potential opportunities at an early age should not be overlooked.

The American system of rewards and pressures seems quite different from that of the Japanese. In our classrooms, there is a strong emphasis on individual competition. Adults expect students to compete for grades within the class, yet peer pressure often discourages students from making a commitment to academic excellence and disparages the "grind." Standardized national exams are less critical here than in Japan, for example, in determining a person's future. There are many different post-secondary institutions with space available and many opportunities for another academic chance in this country. It may well be that such a forgiving system reduces incentive as compared to the anticipation of a once-in-a-lifetime challenge. At the same time, depersonalization and devaluation of the student seem to be problems in many schools, and support of the learning process at home may be decreasing as all family members spend increasing amounts of time away from home.

THE CURRICULUM

Perhaps the two most interesting curricular approaches described in the following chapters are the spiral curriculum in science and math, and the polytechnical concept of general education.

In a spiral curriculum, each science is taught over a period of several years, beginning with concrete experiences to build an intuitive understanding of a subject. Gradually, students progress to practical and more quantitative work and, finally, to abstract, theoretical analysis. The spiral approach is based on psychological theory and research on human learning which has been conducted largely in Europe and the Soviet Union. Applying this research, each science, and geometry and algebra, are typically taught for four or five years. This contrasts sharply with the U.S. practice which allots one year of study per subject. Critics of the spiral system say it is potentially repetitious and boring. Critics of the one-year, one-subject system say that it promotes superficial learning and rapid forgetting. Our performance in recruiting students into science instruction and teaching them effectively is of sufficient concern that we should at least reexamine our curricular approach. What design is best suited for our students and the world they will encounter?

Yet another difference between the United States and East Germany, the USSR, China, and Japan is the latter countries' emphasis on the polytechnical system. That is, instead of separating students into theoretical and applied tracks as we do, all students are required to study both. Soviet children take ten years of shop. In the German Democratic Republic, schools are associated with factories in which students take classes and do productive work. In China, the products of student labor help to

support the school system. In Japan, children perform many of the functions that require paid workers in the United States, such as cleaning rooms and grounds, preparing meals, etc. Is much of this merely child-labor? Or is it an important part of the curriculum, contributing to the morale and group spirit of the class and well integrated with the more theoretical classes?

There has been relatively little empirical research reported in U.S. educational research journals comparing the polytechnical and theoretical approaches. It would be interesting to compare the effects of the two methods along a variety of dimensions, including the following: What knowledge and skills do students have at the end of their educational experience? What are their attitudes toward science and technology? Toward work? What are their "world views"? What are their images of science and scientists? The value of a polytechnical emphasis, most clearly seen in East Germany, seems particularly important to explore. Properly implemented, it may represent a way to incorporate experiential learning into the formal curriculum in a bold and systematic way.

TEACHERS

Whatever the curriculum, its effectiveness depends upon the knowledge and skills of the teachers who must implement it. Well-educated teachers are a necessary precondition for the education of a nation's youth. The attention that a society pays to the selection, education, and rewarding of teachers reveals much about the attitudes of that society toward the entire educational process.

Three aspects of teacher preparation are highlighted in the chapters which follow: teacher specialization, requirements for initial certification, and in-service education. For instruction as early as the fourth grade, teachers are often required to be subject matter specialists. In some countries, science teachers are trained to a level equivalent to an M.S. or Ph.D. degree in their field. Each country has provision for in-service education. Many also use mass-circulation, government-supported journals to help science teachers keep up to date. Russian science teachers are required to take a refresher course at least once every five years and to attend periodic seminars and conferences and weekly discussions of science teaching. Japanese teachers are actively and directly involved in the process of curriculum development, and teacher associations influence the direction of future revisions. And although the Japanese feel that in-service education is still a major problem, their teachers have access to some 200 government-funded science education centers located around the country that offer many opportunities for improvement of skills and science knowledge.

In addition, teachers in these countries are often relieved of extraneous clerical and supervisory tasks so that they can concentrate on their instructional responsibilities. Trained assistants are available to help with audiovisual and scientific demonstrations. Discipline in the classroom is a relatively minor

problem, allowing for greater time-on-task for all. Opportunities are provided outside of school for science projects, clubs, and competitions. Government-supported research institutes study science learning and teaching, and attempt to translate their findings into practical and useful guidance for the educational system. In all of these ways, the value attached to teaching and learning is made clear.

What lessons can we learn from these observations? Could teacher centers, for example, be fruitfully incorporated into our own educational system? Would they be used effectively? How important is it for teachers to have strong preparation in the subjects they teach? How important is time-on-task?

EXAMINATIONS AND THE QUALITY OF LEARNING

An old adage holds that it doesn't really matter what you teach, it's what and how you test that counts. Standardized national exams are the gates through which a society can exert control over what is studied and what skills are developed. Such tests can provide a form of quality control; as such, they represent tangible goals toward which students and teachers can work. National exams are employed in all five of these countries, and there are disadvantages as well as advantages.

The pressure of the Japanese college entrance exams is well known. These exams shape much of the content and style of Japanese schools even though there is no "college preparatory" track. They also influence parental behavior, since parents frequently pay for special courses to help their children prepare for the exams or try to place their children in special schools. Indeed, in Japan children are even given special preparation for entrance exams to kindergarten!

In West Germany, entrance to the university is determined by an examination taken at the end of secondary school, but the precondition is set at age 10, when the child and his or her parents select the track to be taken: Hauptschule, Realschule, or Gymnasium. Only the Gymnasium provides the education necessary to qualify for and to succeed in the college entrance exams.

Exams in the other countries also have a substantial impact on the course of a student's entire life, and the stress associated with such exams is hard for us in the United States to imagine. This is especially true when one considers that universities in these five countries can accept only 5 to 10 percent of the nation's youths, a truly elite minority. One wonders what price is paid in addition to the occasional suicides one reads about. At the same time, there are surely dividends that accrue from raising learning to so serious an enterprise and from the respect that is accorded the students and teachers engaged in it. A change in this direction would be refreshing indeed in the United States.

One wonders if the United States, by making higher education so easily accessible to all, has thereby diminished both the value of such an education and the motivation to strive for it. What is the optimal balance between expectation of high performance and forgiveness of poor performance? We have seen that Japanese youth dramatically out-perform American children on international exams in mathematics and science. To what extent do standardized national exams that control college entrance contribute to enhanced performance at all grade levels?

EQUALITY OF OPPORTUNITY

There appear to be few satisfactory answers regarding equality of educational opportunity. For example, while Russia claims to provide a very high level of scientific education for all, some schools seem to be more equal than others. Connections as well as talent appear to influence entry into preferred schools and prestigious colleges. Similarly, Japan requires a rigorous science education for all students, and their top performance on international exams suggests that they succeed. Ethnic, geographic, and sex differences apparently have a negligible impact on the performance of Japanese children in science at elementary through high school levels, making at least that part of that school system seem exceptionally egalitarian. Yet equality begins to disappear when students are selected for the limited number of places in the most prestigious precollege schools. Even though females perform as well as males through secondary school, males from well-to-do families dominate the student bodies of top-ranking universities. Once again, it appears that social expectations and discrimination against professional working women persuade talented girls not to invest their energies in science. The West German school system seemingly assures perpetuation of a class-oriented society, while the East German system appears to provide considerable opportunity for breaking down class lines.

How strongly can the educational system shape the social structure of society? Do most students typically become aware of unspoken social expectations, make a tacit investment analysis, and allocate their intellectual energies accordingly? How important is the perception of economic reward and social approval to the learning process in the United States? Is this a more powerful explanation for sex and class differences in achievements in mathematics and the sciences than any other consideration? And does the use of the schools to mitigate social inequities necessarily weaken science education programs, unless the society is already relatively homogeneous?

A CLOSING QUESTION

The chapters that follow are rich in the descriptive information and the insights essential for thinking about education in general and science education in particular. Children starting school now will complete college by the beginning of the twenty-first century. Will our educational system have given them the intellectual and practical preparation for a satisfying and effective life in a country still a leader among nations? Clearly, the answer depends on what we do now -- and on what lessons we can learn from both the successes and failures of other nations around the world.

Kay Michael Troost

1. Science Education in Contemporary Japan

INTRODUCTION

Japanese science education is more successful than its American counterpart in terms of both quantity and quality of science education for all students. More students take advanced science courses; the average level of cognitive achievement attained by Japanese students is higher, and so is the level of scientific literacy of the Japanese population as a whole. Some of this success is due to the overall effectiveness of Japanese precollege education, and part is a result of specific features of its science education. In this chapter, I will examine general educational practices, describe the science curriculum at both the elementary and secondary levels, and then conclude by evaluating the strengths and weaknesses of the Japanese educational system.

An interesting irony in the comparison of Japanese and American science education is that since World War II, Japanese education has been based upon the American model. The American Occupation forces attempted to "democratize" Japanese education, and the continuing domestic effort has made it more egalitarian than its American counterpart. In addition, the process of cyclic revision of the curriculum and the ongoing dialogue between the teachers' union (Nikkyōso) and the Ministry of Education, Science, and Culture (Mombushō) has in many instances substantially altered the original curriculum.

An overview of the Japanese educational system is provided in Figure 1.1, and numbers of students, teachers, and institutions are shown in Table 1.1. Due to the reforms of the Occupation, the Japanese replaced their European -- and particularly German-influenced -- system with a 6-3-3-4 year system which directly parallels that of the United States. Virtually all students (99.9 percent) complete the compulsory first nine grades, and 94 percent attend high school. The percentage attending a junior college or university (37 percent) is second only to the United States. Almost 70 percent of high school students are in college- and university-oriented curricula; the remainder are in one of six vocational courses: agriculture (3.8 percent), industry and engineering (10.3 percent), commerce (12.5 percent), fisheries (0.4 percent), home

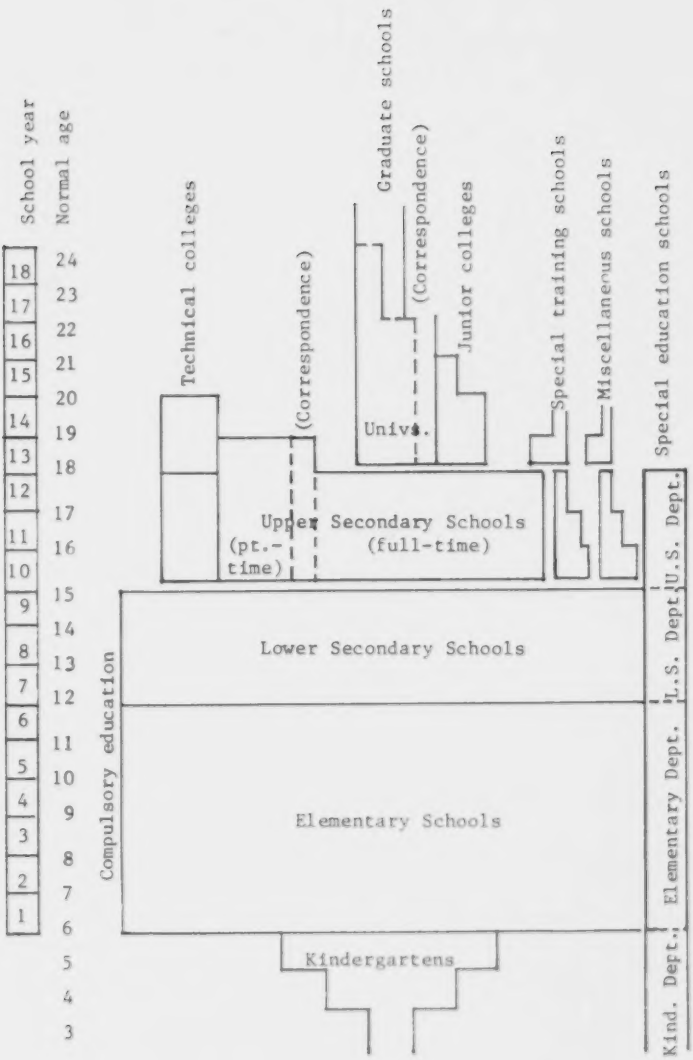

Figure 1.1 Organization of the Japanese school system

Source: Mombushō, Education in Japan (1978), p. 13.

TABLE 1.1
Level by gender for Japanese students, teachers, and institutions[a]

Level of Schooling	Students			Teachers		Institutions		
	Total Enrollment	Percent of Cohort	Percent Female	Total	Percent Female	National	Local	Private
Kindergarten	2,407,113	64.4	48.9	100,960	94.0	48	6,064	8,781
Primary	11,826,574	100.0 99.2[b]	48.7	467,931	56.6	72	24,707	166
Junior high	5,094,402	100.0 99.2[b]	48.8	251,274	32.0	76	10,156	547
Upper secondary	4,621,936	94.2	49.6	243,627	17.9	17	3,959	1,246
Technical college	46,348		2.0	3,721	0.8	54	4	4
Junior college	371,125		89.0	16,372	38.6	35	50	432
University	1,835,304	37.4	22.1	102,985	~8.4	93	34	319
Graduate[c]: M.A.	36,164	4.4[b]	11.6					
Ph.D.	17,103	5.2[d] 1.6[e]	7.9			77	21	159

Source: Mombushō, Mombushō (1981), pp. 13, 15, 17, 18; see also National Institute for Educational Research, Basic Facts and Figures about the Educational System in Japan (Tokyo, March 1982).

[a]Data are for May 1980 unless otherwise noted.
[b]Data from Foreign Press Center of Japan, Education in Japan (1978), p. 30.
[c]Data for graduate students from Mombushō, Mobutōkeiyōran (1979).
[d]Male.
[e]Female.

economics (3.5 percent), and nursing (0.6 percent).

The junior college and technical college systems are much smaller than the university system, with 371,125; 46,348; and 1,835,304 students, respectively,[1] and are more sex segregated. Junior colleges are predominantly female (89 percent), while technical colleges are overwhelmingly male (98 percent).[2] The course of study also varies: the technical colleges are oriented toward the training of technicians, while junior college students are much more likely than their university counterparts to major in home economics or pedagogy (24.4 percent versus 7.9 percent) and, to a lesser degree, humanities. By contrast, university students are apt to major in natural science (3.1 percent versus zero), social science, and engineering (19.4 percent versus 5.9 percent).[3]

The Japanese educational system is highly centralized through the Ministry of Education, Science, and Culture (Mombushō), which controls textbook approval, school accreditation, teachers' salaries, educational subsidies, and the all-important course of study. The minimum course content is specified in considerable detail all the way through high school. Because of the national uniformity, considerable economies of scale in textbooks, curriculum planning, and curriculum-based research are achieved.

The Mombushō bureaucrats in Tokyo also set the requirements for university majors, for postgraduate education, and for the minimum qualifications for faculty members at all levels of school, from day care to postgraduate education. One of the battles which the U.S. Occupation did not win in its reform of Japanese education was an attempt to decentralize the system. Today, Japanese education owes its many strengths and assorted deficiencies to the heavy involvement of the Mombushō in educational affairs at all levels.

The course of study specifies a large quantity and a high level of cognitive content, although many schools supplement it. The course of study sets the minimum -- and it is a very high minimum, internationally speaking -- and is met virtually everywhere. The Mombushō's influence is pervasive: if the classroom is second grade science and it is spring, then the students will be studying sunflowers; if the topic is morning glories, then the class must be first grade. The minimums are met not only due to the vigilance of the central bureaucrats with their financial power, but also due to the professionalism of local school authorities and the demands of parents anxious that their children not be at a disadvantage in the national exams. The Mombushō finances all of compulsory education, including free textbooks which become the property of the student;[4] there are no supplementary fees. Thus, the Mombushō achieves a considerable degree of planned uniformity through the compulsory first nine grades of school.

The financing of education is an important part of national and local budgets. In 1976, for example, 12.3 percent of national expenditures and 27.3 percent of local expenditures were for education.[5] Since then, there has been continued growth in the

Mombushō budget. In 1980, the budget for education was 4.267 trillion yen; in 1981, the budget was 4.854 trillion yen.[6] Dr. S. Okuda estimated the 1982 Mombushō budget at 5.022 trillion yen.[7]

Personnel and capital costs of education differ between Japan and the United States. Cummings cites Mombushō data indicating that Japan spends a larger fraction on capital expenses than the United States, the United Kingdom, or France.[8] While personnel costs in Japan were but 46.5 percent of total educational expenses (compared to 58.6 percent in the United States), capital investment was 28.7 percent (compared to 12.1 percent in the United States).

One reason why personnel costs are low is that student-teacher ratios are high (Japan, 27; U.S., 22). More importantly, very few auxiliary personnel are employed. In Japan, students and teachers perform many of the tasks which in American schools are set aside for support personnel or specialists. For example, many clerical and counseling tasks are handled by Japanese teachers, while Japanese students deliver and serve lunches, clean classrooms and grounds, and operate school facilities such as the library and public address system.[9] This unpaid labor cuts down significantly on costs and is viewed as part of the moral curriculum.

Equality of Opportunity in Education

Following World War II, the American Occupation forces were charged with bringing democracy to Japan, and one of the key areas they attempted to reform was education. Working through Section Head Mark Orr and Science Education Officer Vivian Edmiston Todd, the Americans encouraged financial aid and confirmed a selection system based on merit, as measured by entrance examinations.[10]

Today, the Mombushō administers a number of school finance programs designed to increase the degree of equality in education. These programs give aid to poor regions and provide a variety of scholarships to minority and disadvantaged children. There are also programs of assistance for school attendance at the compulsory level and at upper secondary schools, including part-time, correspondence, and technical schools.[11] These programs range from busing for students with great distances to travel to tutoring and income supplementation to keep academically and financially marginal students in school. Even at the university level, financial need is not allowed to prevent a student from attending a national university if entrance exams have been passed satisfactorily.[12]

The Nikkyōso, a progressive union reflecting teachers' goals, acts as a counterweight to the Mombushō and the conservative direction of the Liberal-Democratic Party (LDP), the ruling party of Japan. While the LDP and Mombushō control finance and curriculum, including textbooks and course of study, the Nikkyōso influences school and classroom activities and the supplementary curriculum arranged by the school or individual teacher.[13] The Mombushō has responded to the needs of industry for a skilled workforce and has

stressed vocational and technical training. The Nikkyōso is less utilitarian and more egalitarian than the Mombushō. Explicitly socialist in ideology, it has stressed full equality of opportunity, compensatory aid, and minority rights.[14] It has been hostile to tracking either within schools or to de facto tracking such as, in its view, vocational education. As the articulator of progressive values, it has stressed "whole person education," science for understanding, the creative use of science, and the impact of science on the world. In sum, the Mombushō and Nikkyōso have each acted to quell the excesses of the other; their partnership, albeit an uneasy if functional one, has, in my opinion, yielded better results than either would have alone.[15]

Equality of opportunity is important because educational attainment is fundamental to financial and occupational success in Japan. If in the United States educational attainment is important to advancement, in Japan, educational success -- attending the right university -- is <u>essential</u> to occupational and financial success. Attendance at National Universities or the best private universities is necessary for advancement to positions of leadership in business and in the highly respected civil service; job entry and advancement are both severely limited for those whose low scores on merit exams preclude education at an elite university.

Because success is so important, entrance to high schools with a reputation for fostering success is very competitive. While school attendance at the compulsory level is guaranteed, high schools, even though supported by public funds, admit only those who can pass their entrance exams. No student is guaranteed a position in a college preparatory course or even in a vocational program unless he or she can earn it on entrance exams. This leads to the "examination hell" of the university being transferred to the lower levels. It becomes important to attend a good junior high, and a good primary school as well. In fact, some parents tutor their pre-kindergarten children in the Japanese syllabary and the Roman alphabet so they can gain entrance into a school that is attached to an elite public or private university. Thus, school success, so essential for access to the ladders of financial and occupational success, requires a vast amount of effort over an extended period of time.

If government policy and the Nikkyōso have attempted to foster equality of educational opportunity, several features of the system have been used by individuals and their families to promote inequality. In addition to heredity, private schools, private tutors, and private, after-school, cram-course schools (juku) all promote inequality of outcome.

Especially within a meritocratic system, a somewhat spurious association will exist between parental income, which is in part caused by parental intelligence, and a child's intelligence or score on a standardized entrance examination. Following Jencks, a 10 to 20 percent association between parental income and child's intelligence seems reasonable, which would account for perhaps half

of the association of math and science scores discussed in the following section.[16]

Precollege private schools exist primarily to provide higher quality education for a much higher price than the parallel public institutions. Some do provide a sheltering function for those children of the well-to-do who, having passed an entrance examination perhaps as early as kindergarten, may remain within the private school all the way through the university level if they do satisfactory work. Certainly, a chief reason for parents to pay the much larger fees for private school is that they promote success in university entrance examinations (see Table 1.2). Success on entrance examinations at all levels of precollege education is also aided by juku.[17] Attendance at after-school juku is larger in urban areas, where school competition is most intense, and varies by level, with as many as one-fourth of primary school students, one-third of junior high school students, and a still larger percentage of high school students in attendance at any one time. Most students attend juku at some time during their school careers. Linked to juku for university entrance are rōnin, that is, students who, having failed to pass the entrance examinations for the university of their choice, spend the next year studying so they can make a second try.

Both juku and rōnin illustrate how high-income parents can aid their children's educational advancement. Especially in the case of rōnin, it requires greater sacrifice by a poor family than for a well-to-do family to finance a second or third try for admission to such a pinnacle of higher education as Tokyo University. Because great numbers of students compete for entrance to elite schools, a small edge may prove critical in gaining entrance; thus, at the extremes of family background, the advantage may be more salient than for the middle of the range. Alternatively, given the high quality of Japanese schools and the fixed amount of student time, the university entrance examination system ensures considerable equality of opportunity, if not full equality of result; family wealth cannot directly buy entrance to a major university.

The first study by the International Association for the Evaluation of Educational Achievement (IEA), completed in 1973, indicates that family background does influence cognitive achievement to a moderate degree.[18] The Japanese mathematics achievement was the highest of the twelve countries studied;[19] in science achievement, the Japanese had the highest average score in the larger sample of nineteen countries.[20]

Cummings reanalyzed the IEA mathematics data and found a path of .251 between parental status and cognitive achievement in mathematics among 13-year-olds in Japan, while it was .280 in the United States.[21] The correlation of father's occupation and cognitive achievement in science among 14-year-olds was .24 in Japan, .31 in the United States, and .19 in West Germany.[22] However, in terms of variance, the Japanese association is only 60 percent of the American one.[23] Given this spurious association, we can conclude that for Japanese science education at the secondary

TABLE 1.2
Tuition and other fees in Japanese schools[a]

Classification		Kinder-garten	Elem. School	Lower Sec.	Upper Sec.	Tech. College	Junior College	Univ.
National	Tuition fee	33,600	--	--	45,600	80,400	132,000	180,000
	Entrance fee	9,600	--	--	16,000	24,000	48,000	80,000
	Facilities & equip-ment support, etc.	--	--	--	--	--	--	--
Public	Tuition fee	38,840	--	--	59,643	80,400	113,216	160,588
	Entrance fee	817	--	--	1,358	10,400	69,727	119,000
	Facilities & equip-ment support, etc.	--	--	--	--	--	--	--
Private	Tuition fee	121,494	184,092	196,567	166,863	241,000	251,831	355,156
	Entrance fee	34,552	111,542	119,459	98,866	149,375	166,784	190,113
	Facilities & equip-ment support, etc.	19,983	134,974	124,974	98,997	55,625	137,128	159,621

Source: Mombushō, Mombushō (1981), p. 88.

[a]Figures are in yen, where approximately 240 = $1.00 U.S.

level, there is substantially greater equality of opportunity than in the United States.

Equality of Opportunity: Gender

The lower correlation for Japan between father's occupation and achievement in the IEA data suggests greater equality of opportunity for Japanese students, which is in sharp contrast to Japan's prewar elitism. Historically, Japan was also a society with profound gender inequality. This situation has changed considerably over the past few decades, particularly in education, where enrollment of males and females remains equal at least through high school (see Table 1.1.)

Nevertheless, clear differences in levels of achievement emerge as men and women progress through Japan's educational system.[24] Cummings, whose observations are made for compulsory education, indicates there is equality of treatment for boys and girls, and that there is rough equality of result even in science and mathematics.[25] Comber and Keeves also found little difference in the science achievement of Japanese boys and girls in primary school.[26] Thus, at the primary school level, there is not only formal equality of opportunity, but also equality of result in terms of learning. By the end of junior high school, however, clear differences in cognitive achievement by subject appear,[27] and by the time of the college entrance examinations, the most crucial step for educational and occupational advancement, men and women take decidedly different paths. Fewer women take or pass the exams, and women are less likely to gain entrance to the elite institutions, such as Tokyo University, and thus are much less likely to occupy positions of leadership later in life.

The inequality of result in higher education in Japan is a social phenomenon, not a de jure one. Educationally, it is the perceived difficulty of college entrance exams and the unwillingness of young women and their families to support the tremendous amount of effort and the great expense of special tutors needed to pass the exams; this difference more than any other accounts for the gap between men and women -- especially at elite institutions. But differences in the way men and women are socialized also take their toll. Just as the social expectations for men and women are different, so too are their self-perceptions. Women are expected to make a choice between career and marriage, and society does expect that a woman will "retire" from her occupation at a young age -- usually upon marriage, but certainly upon the birth of the first child.

SCHOOL AND CLASSROOM PROCEDURES

School Procedures

During compulsory education, there is no tracking of students within schools. All students throughout the country study the same curriculum, and within classes, all students are expected to achieve equal mastery. The Nikkyōso and concerned parents reinforce this goal, and the most recent revision of the curriculum, which reduces the volume of material to be learned, shows that the Mombushō has accepted this goal as well. Tracking into different curricula does occur at the high school level for the 30 percent of students who choose one of the vocational educational curricula. However, since nearly 95 percent of each cohort goes through high school, a majority of Japanese students master the general curriculum relatively equally. Husen and Comber and Keeves all found that the average dispersion of achievement within classrooms in Japan was lower than that for most other nations.[28]

Yet, while there is no tracking or assigning of students to different curricula based on ability (i.e., scores on a standardized test), this does not mean that all students are exposed to identical situations in school, even at the compulsory level. Within any school, it is reasonable to suppose that students receive a similar education, but there are differences among schools. Although there is relatively little difference in achievement levels among primary schools, by the end of compulsory education there are considerable differences in school averages on achievement tests. In one test administered by the Mombushō, for example, the range was eighty points on a one-hundred point test.[29] This large range is acknowledged as a problem by the Mombushō, and is one reason why the content of the curriculum has been reduced in volume.

Despite the pressure for educational equality in compulsory education, the structure of Japanese society as a gakureki shakai -- a school- or examination-regulated society -- is one reason for this difference among schools. Far more than in other societies, high income and status in Japan require attendance at a quality university. Entrance to private and national schools is regulated by examination, and Japanese schoolchildren spend a great deal of effort, and are strongly supported by their families, in preparing for these examinations.

To enter a prestigious national university, one must pass an extremely taxing and competitive two-stage entrance exam.[30] To enter a prestigious private university, one must either pass that university's entrance exam or be a graduate of the attached high school, entrance to which is similarly regulated. Indeed, fine private university-attached schools have entrance examinations for kindergarten, and parents may drill their preschool children strenuously for them. While the entrance examinations are an example of the meritocratic character of contemporary Japan, they have a significant impact on the society, on the schools, and on youth. The examination system represents a monument to lost youth.

Classroom Procedures

What, then, is the effect of both egalitarianism and examination-system competition upon classroom procedures? At the primary school level, one is struck by the high degree of warmth in the relationship between students and teachers.[31] Here, grades are not important, since quality control is maintained by standardized examinations and by the Mombushō's regulation of the course of study. And because examinations do have such a determinative impact on students' lives, inferior methods of teaching are strongly discouraged by teachers, students, and especially parents.

Competition for a high score on an examination does not translate into competition within the classroom: once a student is in a school, he or she does not have to compete to maintain his or her place at the school, assuming normal progress. Moreover, in most cases, neither class rank nor grades will be considered in his or her application to college.[32] Consequently, competition is not with one's classmates but with the thousands of other students who are taking the same entrance examination. In contrast to American schools, where competition is primarily with other students in a particular classroom, the Japanese system deemphasizes in-class competition in favor of a warm, familistic classroom and encourages competition with an unseen mass of others, that is, in-class cooperation and outgroup competition.[33] Students and teachers, individually and collectively, cooperate to see that everyone achieves relatively equal mastery of the course material. The model adopted in the early postwar period of ability being the key to learning has given way to a theory that stresses hard work. Entrance examinations are not seen as indicators of ability or potential or brightness; rather, they are viewed as measures of what the student has learned.

When observing Japanese classrooms, one is struck by how comparatively little effort is spent on discipline, order, and the like. One researcher found that, when compared to the United States, Japanese teachers spend a greater amount of time and effort on achieving class order in the early grades and that they reap the benefits in later years.[34] My own observations suggest that several factors may be at work. In the first couple of years, teachers do spend a good deal of energy controlling students, but they are also very supportive. In fact, support acts -- encouraging students to work hard, congratulating them on mastery of material, or just a warm acknowledging of the personhood of the student ("whole person education" is a key phrase of the teachers' union) -- outnumber control acts. By third or fourth grade, however, task acts -- presentation of material, explanation, and so forth -- outnumber both support and control activities. In the early grades, teachers count more heavily on the involvement of families in the child's education. Primary school students are given a lot of homework, and teachers depend on parents, parentally hired tutors, or juku to help students master the coursework.

Moral education also plays a role in maintaining classroom order. Japanese classrooms tend to be arenas for learning rather

than places where elders assert control over juniors, or where the teacher's major function is babysitting. The Japanese concept of moral education is not the same as the Christian view of morality; in Japan, the concern is with interpersonal ethical problems such as how one should treat others to preserve their dignity and self-respect as equals. Moral education strenghthens the values of productive labor, hard work, civility, and responsibility, which aids in the pursuit of knowledge in the classroom as well.[35]

Japanese students are given other duties that reinforce the responsibility they feel toward their school and their classmates. As mentioned earlier, students keep the classrooms and halls clean and, in the process, learn respect for school facilities, which may account for the low level of vandalism. School uniforms increase not only school identity but also the accountability of students outside the school. Uniforms also help family budgets and minimize the opportunity for parental income to play a large role in the school. In primary school, classes typically stay with the same teacher for two years, which strengthens the sense of class identity and aids in the development of in-class warmth. Kiefer notes the socioemotional compatibility of classroom and family, and suggests that this may be greater in Japan than in the United States due in part to the home environment.[36] In my own work in both the United States and Japan, I have seen a clear relationship between the degree to which students perceive "congruity" between home and classroom environments and their liking for and achievement in science.[37]

GENERAL CURRICULUM

As discussed earlier, the Mombushō maintains control over the educational system in Japan through a variety of measures. Among the most important are the development of the curriculum and the setting of school standards. But not only does the Mombushō set the general requirements, it also specifies course content from first grade through high school via the official course of study. The Nikkyōso, individual teachers and administrators, parents, and others exert influence through the process of periodic revision of the curriculum as well as within the confines of a particular school or classroom.

Table 1.3 shows the standard number of periods per year for each subject in primary school. At this level, Japanese language is the largest component, with arithmetic second, physical education third, and science and social studies tied for fourth in terms of percentage of time in the curriculum. Grouping similar types of subjects together yields the following picture for primary school: science and arithmetic, 45 credits or periods per week; Japanese language, 44; arts, music, and homemaking, 28; physical education and social activities, 27; and social studies and moral education, 22. Rankings, of course, depend upon the grouping.

Table 1.4 presents the curriculum for lower secondary school. Together, mathematics and science represent the largest portion of

the curriculum, although more hours are spent on Japanese language than either alone. A sizable number of credits are required in social studies and health and physical education, and a similar number are open to elective subjects. Table 1.5 shows the course offerings in upper secondary school, and Table 1.6 shows the required courses under the old and the revised curricula.

Course requirements in compulsory education are summarized by subject area in Table 1.7. Note that science and mathematics, with 25.8 percent, constitute the largest proportion of the requirements, while smaller percentages are allotted for Japanese language (22.3 percent), arts (17.6 percent), physical education (16.4 percent), and social studies (14.1 percent). In the very early years of school, Japanese language training is stressed, but after the second grade, science and mathematics catch and then surpass language training, thereafter constituting the largest proportion of the curriculum.[38] Save for the emergence of elective subjects in the last portion of compulsory education, subject areas remain stable in terms of the fraction of the curriculum devoted to them. (See Table 1.8.)

Primary school teachers in Japan teach between 21 and 27 class hours per week, junior high school teachers between 17 and 21 hours, and senior high school teachers between 14 and 17 hours.[39]

THE SCIENCE EDUCATION CURRICULUM

When the American Occupation, in cooperation with the Japanese, developed the postwar science education curriculum, the general thrust was to "democratize" the system. Other goals were to increase teacher flexibility, decrease the emphasis on rote learning, and institute periodic review cycles to evaluate the effectiveness of the curriculum. The science curriculum, under the guidance of science curriculum specialist Vivian Edmiston Todd, stressed observation, experimentation, and the development of positive feelings for science over the learning of specific facts.

The first curriculum was used for about ten years and was pragmatic in orientation; learning-by-doing and the experimental approach were stressed along with applications to daily life. The second curriculum, which lasted nearly twenty years, maintained the emphasis on application but also become more discipline-centered and inquiry- and problem-oriented. Greater emphasis was placed on the use of educational psychology. Because this curriculum was addressed more explicitly to the manpower needs of the society, it was considered less "democratic." The third — and short-lived — curriculum revision began with a reevaluation of teaching practices in light of an increasing number of dropouts from science courses, a growing concern for the societal issues of science such as pollution, and a belief that progress should not be made at the expense of humanity. The fourth curriculum revision continues the emphasis on the social problems of science, and also takes into account the awareness that the knowledge-centered curriculum had become too large

TABLE 1.3
National standard teaching periods of subjects in Japanese primary schools

Subject	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Total Periods	Total Credits
Japanese lang.	272 (8)[a]	280 (8)	280 (8)	280 (8)	210 (6)	210 (6)	1532	44
Social studies	68 (2)	70 (2)	105 (3)	105 (3)	105 (3)	105 (3)	558	16
Arithmetic	136 (4)	175 (5)	175 (5)	175 (5)	175 (5)	175 (5)	1011	29
Science	68 (2)	70 (2)	105 (3)	105 (3)	105 (3)	105 (3)	558	16
Music	68 (2)	70 (2)	70 (2)	70 (2)	70 (2)	70 (2)	418	12
Art & crafts	68 (2)	70 (2)	70 (2)	70 (2)	70 (2)	70 (2)	418	12
Homemaking	--	--	--	--	70 (2)	70 (2)	140	4
Phys. education	102 (3)	105 (3)	105 (3)	105 (3)	105 (3)	105 (3)	627	18
Moral education	34 (1)	35 (1)	35 (1)	35 (1)	35 (1)	35 (1)	209	6
Special activ.	34 (1)	35 (1)	35 (1)	70 (2)	70 (2)	70 (2)	314	9
TOTAL	850 (25)	910 (26)	980 (28)	1015 (29)	1015 (29)	1015 (29)	5785	166

Source: Adapted from Masao Miyake, "National Science Curriculum Case Studies," unpublished paper, National Institute for Educational Research (Tokyo, 1981), p. 6. See also Mombushō, Mombushō (1981), p. 22.

[a]The number in parentheses indicates the number of periods per week or "credits," where each period represents 45 minutes. While the Mombushō does not, in its statistics, use this designation for compulsory education, it is useful for making comparisons across levels. In first grade, there are 34 actual teaching weeks, while in grades two through six, there are 35.

TABLE 1.4
Standard teaching periods in Japanese lower secondary schools

Subject	Grade 7	Grade 8	Grade 9	Total Periods
Japanese language	175 (5)[a]	140 (4)	140 (4)	455 (13)
Social studies	140 (4)	140 (4)	105 (3)	385 (11)
Mathematics	105 (3)	140 (4)	140 (4)	385 (11)
Science	105 (3)	105 (3)	140 (4)	350 (10)
Music	70 (2)	70 (2)	35 (1)	175 (5)
Arts	70 (2)	70 (2)	35 (1)	175 (5)
Health & phys. ed.	105 (3)	105 (3)	105 (3)	315 (9)
Industrial arts & homemaking	70 (2)	70 (2)	105 (3)	245 (7)
Moral education	35 (1)	35 (1)	35 (1)	105 (3)
Special activities	70 (2)	70 (2)	70 (2)	210 (6)
Elective subjects	105 (3)	105 (3)	140 (4)	350 (10)
TOTAL	1050 (30)	1050 (30)	1050 (30)	3150 (90)

Source: Adapted from Mombushō, Mombushō (1981), p. 22.

[a]The number in parentheses indicates the number of periods per week or "credits," where each period represents 50 minutes.

TABLE 1.5
Subject areas, subjects, and standard number of credits required at upper secondary schools in Japan

Subject area	Subject	Standard Number of Credits Required[a]
Japanese language	Japanese language I	4
	Japanese language II	4
	Expression in Japanese language	2
	Modern Japanese	3
	Classics	4
Social studies	Contemporary society	4
	Japanese history	4
	World history	4
	Geography	4
	Ethics	2
	Politics & economics	2
Mathematics	Mathematics I	4
	Mathematics II	3
	Algebra & geometry	3
	Analytical geometry	3
	Differentiation & integration	3
	Probability & statist.	3
Science	Science I	4
	Science II	2
	Physics	4
	Chemistry	4
	Biology	4
	Earth sciences	4
Health and physical education	Physical education	7-9
	Health	2
Arts	Music I	2
	Music II	2
	Music III	2
	Fine Arts I	2
	Fine Arts II	2
	Fine Arts III	2
	Industrial Arts I	2
	Industrial Arts II	2
	Industrial Arts III	2
	Calligraphy I	2
	Calligraphy II	2
	Calligraphy III	2

TABLE 1.5 (continued)
Subject areas, subjects, and standard number of credits required at upper secondary schools in Japan

Subject area	Subject	Standard Number of Credits Required
Foreign language	English I	4
	English II	5
	English II-A	3
	English II-B	3
	English II-C	3
Home economics	General home economics	4

Source: Mombushō, Mombushō (1981), p. 23.

aOne credit consists of 35 unit hours in the course of one school year, one unit hour being 50 minutes of teaching.

Note: Under the Arts subject area, one subject is to be chosen for study from among Music I, Fine Arts I, Industrial Arts I, and Calligraphy I. Also, General Home Economics is to be studied by all students.

Apart from the subject areas and subjects shown in the table, there are, at upper secondary schools, subjects which belong to subject areas for specialized education (foreign languages, home economics, agriculture, industry, commerce, fisheries, nursing, science and mathematics, physical education, music, arts, and English). In the courses oriented mainly to specialized education, the number of credits required from all pupils in the respective subject areas and subjects for specialized education should not be less than 30.

The total number of credits required before graduation should be 80 or more.

TABLE 1.6
Required subjects in Japanese upper secondary schools

Subject Area	Required Subjects According to Revised Course of Study[a]	Required Subjects According to Former Course of Study[b]
Japanese language	Japanese Language I (4)	Modern Japanese (7) Classic I - A (2)
Social studies	Modern Society (4)	Ethics & sociology (2) Political science & economics (2) and 2 subjects from: Jap. history (3), world history (3), Geography A (3) or B (3)
Mathematics	Mathematics I (4)	General mathematics (6) or Mathematics I (6)
Science	Science I (4)	Basic science (6) or 2 subjects from: Physics I (3), Chemistry I (3), Biology I (3), Earth Science (3)
Health & physical education	Physical education (7-9)[c] Health (2)	Same as Revised Course of Study

[a]Effective from the 1982 school year.
[b]Effective until 1981.
[c]Male students in full-time courses must acquire 11 credits.

Note: Figures shown in parentheses represent the number of credits to be earned before graduation from an upper secondary school course.

TABLE 1.6 (continued)
Required subjects in Japanese upper secondary schools

Subject Area	Required Subjects According to Revised Course of Study[a]	Required Subjects According to Former Course of Study[b]
Arts	One subject from: Music I, Fine Arts I (2), Handicraft I (2), Calligraphy I (2)[d]	Same as Revised Course of Study
Home economics	General home economics (4)[e]	Same as Revised Course of Study

[d]Full-time course students must acquire 3 credits.
[e]For female students only.

One credit consists of 35 class hours. A class period of 50 minutes is defined as one class hour. Total number of subjects to be learned by a student is 7 (8 for females), according to the Revised Course of Study. Total number of credits to be earned in the required subjects is 32. To complete the upper secondary school course, students earn 80 credits (each of 35 class hours). This is true for regular students, as well as part-time and correspondence students. For vocational or other specialized courses, 30 of the 80 credits must be earned in the specialized area. (See National Institute for Educational Research, Basic Facts About the Educational System in Japan (Tokyo: March 1982), p. 19.)

TABLE 1.7
Percent of curriculum in subject areas, by grades, in Japan

Subject Area	Grades[a] 1-2	3-4	5-6	1-6	7-9	1-9
Science & arithmetic	25.5 (13)[b]	28.1 (16)	27.6 (16)	27.1 (45)	23.3 (21)	25.8 (66)
Japanese language	31.4 (16)	28.1 (16)	20.7 (12)	26.5 (44)	14.4 (13)	22.3 (57)
Arts, music, home ec.	15.7 (8)	14.0 (8)	20.7 (12)	16.9 (28)	18.9 (17)	17.6 (45)
Physical education & special activities	15.7 (8)	15.8 (9)	17.2 (10)	16.3 (27)	16.7 (15)	16.4 (42)
Social studies, moral education	11.8 (6)	14.0 (8)	13.8 (8)	13.3 (22)	15.6 (14)	14.1 (36)
Elective subjects	--	--	--	--	11.1 (10)	3.9 (10)
TOTAL	100.1 (51)	100.0 (57)	100.0 (58)	100.1 (161)	100.0 (90)	100.1 (256)

Source: Adapted from Mombushō, Mombushō (1981), p. 22. See also Tables 1.3, 1.4, 1.5.

[a]The two-year grouping of primary grades corresponds to Japanese convention.
[b]The numbers in parentheses are the credits in that area.

TABLE 1.8
Number of periods in curriculum, by subject area, in Japan

Subject Area	Grades 1-6	%	Grades 7-9	%	Grades 1-9	%
Science	558	9.6	350	11.1	908	10.2
Arithmetic/math.	1011	17.5	385	12.2	1396	15.6
Science & arith.	1569	27.1	735	23.3	2304	25.8
Japanese language	1532	--	455	--	1987	--
Arts, music, home ec.	976	--	595	--	1571	--
Phys. ed. & special activities	941	--	525	--	1466	--
Social studies & moral education	767	--	490	--	1257	--
Elective subjects	--	--	350	--	350	--
TOTAL	5785[a]	--	3150[b]	--	8935	--

Source: Adapted from Mombushō, Mombushō (1981), p. 22.

[a]45 minute periods.
[b]50 minute periods.

for most students to master. The overloading of the curriculum had been building for a number of years and was in part a response to the examination system. However, the problem had reached the point that upper level courses, which had been originally devised for less than half the population, were having to be mastered by nearly everyone. The fourth curriculum revision reduces the amount of material to be taught, rearranges the order in which courses are taught, and institutes a single introductory high school science course, to be taken before all other specialized courses.[40]

The thrust of the four postwar science education curriculum revisions has been to blunt the American character of the system and return it to a more Japanese form. While those aspects supported by Japanese teachers and administrators have been retained, much else has been eliminated. It seems as though primary school, with its emphasis on observation and experimentation, has probably remained closest to its earlier form, while high school, with its proximity to university entrance exams, has become memory-oriented and is strongly teacher-centered.

Figure 1.2 shows the distribution of required science and mathematics instruction in Japan. While the curriculum is fixed for compulsory education, there is considerable leeway in elective science courses in upper secondary school, even in the general curriculum, which is oriented to university entrance and is taken by 80 percent of the students. In the first two years of school, there are two periods of science; for the next six years, science classes meet three times per week. Nearly 10 percent of compulsory education is in science, and arithmetic and mathematics constitute over 15 percent of the curriculum. In upper secondary school, a typical student takes 11 credits of science (out of a total of 80), although the minimum science requirement is only 4 credits.[41]

Primary School Science Education

Primary school science, with its emphasis on observation and experimentation, contrasts sharply with education in later years. Professor Shigekazu Takemura, formerly head of the Mombushō's science curriculum, uses such phrases as "science play" and "do-it-yourself fun" to describe his perspective. Under his direction, the curriculum encouraged children to awaken and strengthen their curiosity, to be active in their manipulation of objects, and to use all five senses. Other key phrases of his methodology included "autonomous learning" and "interpretation of discrepant events." Teachers were encouraged to question rather than supply ready-made answers and to demonstrate that incompleteness encourages learning. Science laboratories were built in virtually every primary school, and 75 to 80 percent of schools now have at least two.

Paralleling Titchener's belief that observation is the basis of science,[42] so the Japanese student begins his exposure to science in first grade with observation. Textbooks in the early

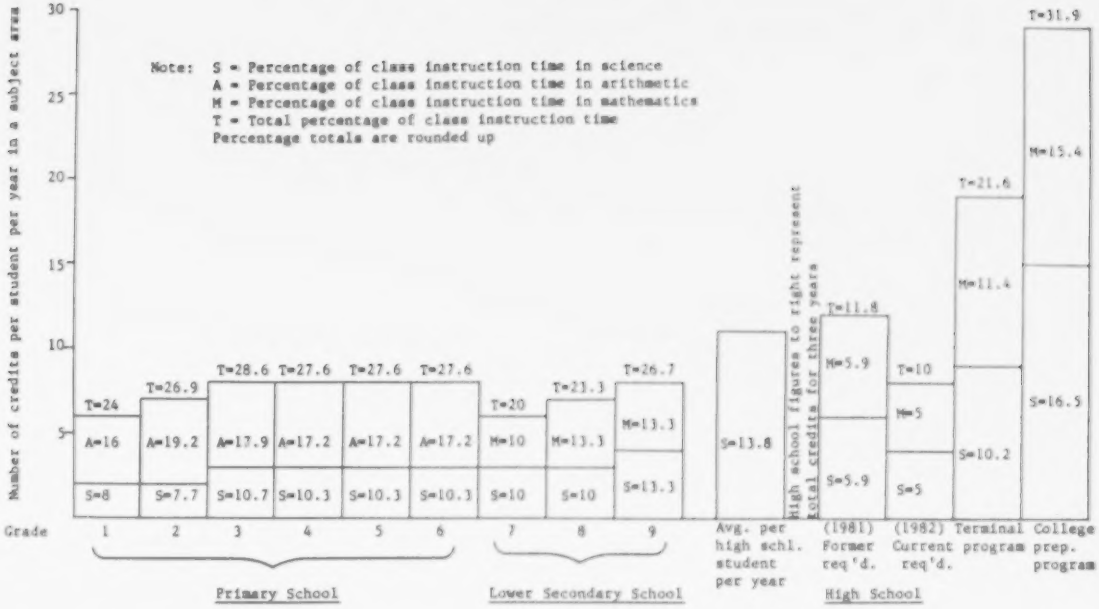

Figure 1.2 Distribution of required science and mathematics instruction in Japan

Sources: Mombushō, Course of Study for Upper Secondary Schools in Japan (1976) and Mombushō (1981); Masao Miyake, "National Science Curriculum Case Studies," unpublished paper (1981), National Institute for Educational Research (Tokyo); Ronald S. Anderson, Education in Japan, Government Printing Office (Washington, D.C., 1975), pp. 150-51; Hideo Ohashi, "Evaluating Curriculum Change in Japan," Journal of Science Education in Japan (1980) 4:129-38.

grades encourage this type of inquiry, and their form and layout are conducive to learning. The texts are softcover, with beautiful color illustrations, and are lightweight, which facilitates children taking their books home with them each night. The books are furnished free of charge, and children typically have two or three science texts each school year.

Although the books are published by private companies, they are closely based on the Mombushō's course of study. The topics addressed in the texts are wide ranging, but carefully ordered so that topics recur several times within the first few years of instruction. This serves to reinforce learning, but more importantly, it allows the development of progressively more sophisticated perspectives on the material within the "spiral curriculum." Since the same course of study guides the whole country, research on methods and materials can be efficiently coordinated. Students who move do not find themselves at a disadvantage, because the same basic structure is used in schools throughout the country. While the first and second grades are oriented toward plants, animals, objects, and phenomena of everyday life, topics covered during the next four years exemplify both the spiral nature of the curriculum and the expansion of coverage (see Table 1.9). Of course, a potential disadvantage of the spiral approach is that students may become bored if the material is repetitious or does not develop sufficiently rapidly to provide challenge.[43] Table 1.10 shows how the teaching content of the fourth grade has been reduced in the fourth curriculum revision.

Lower Secondary School Science Education

The curriculum for lower secondary school provides a transition from primary to upper secondary levels, although the orientation is probably closer to the higher level. The texts, still softcover, are increasingly verbal and are illustrated largely in black and white. The method of teaching tends to be teacher-dominated. The material to be covered is extensive, and bears more similarity to the knowledge-centered upper secondary level than to the warm, intuitive orientation of primary school. As an index of this transition, Miyake estimates that one-third of class time in fourth grade is devoted to observation and experimentation;[44] by seventh and eighth grades, the fraction falls to one-seventh. Advanced science courses in eleventh and twelth grades, under the looming presence of university examinations, spend only one-eighth of their time on observation and experimentation.

The science content in junior high school is heavy, consisting of two areas, one in physics and chemistry and the other in biology and earth science (see Table 1.11). When the IEA compared Japan to eighteen other countries, including the United States and West Germany, it scored the Japanese course of study highest in terms of presenting students with an "opportunity to learn;" that is, Japanese students are exposed to more topics than students in any other country. But the large volume of material to be learned -- as well

TABLE 1.9
Number of items covered under each teaching content in Japan

Part	Teaching Content	Grade 3	4	5	6	Total Per Subj.
A. Living things and their environment	Plants	2	1	2	2	7
	Animals	1	1	1	-	3
	Human body	-	-	-	1	1
B. Substance and energy	Aqueous solution	-	1	1	1	3
	Substance	-	-	1	1	2
	Air	1	-	-	-	1
	Forces	1	1	-	1	3
	Heat	-	1	-	1	2
	Magnet	1	-	-	-	1
	Electricity	-	1	-	1	2
	Light	1	-	1	-	2
	Sound	-	-	1	-	1
C. The Earth and universe	Weather	2	-	1	1	4
	Rocks & soil	-	1	-	1	2
	Celestial body	-	1	-	-	1
TOTAL per grade		9	8	8	10	35

Source: Masao Miyake, "National Science Curriculum Case Studies," unpublished paper, National Institute for Educational Research (Tokyo, 1981), p. 7, citing Kunio Umeno, "Short Report on the Out-of-School Science Activities in Japan," unpublished paper, NIER (Tokyo, June 1981).

TABLE 1.10
Teaching contents of the fourth grade in Japan

I. 1971-1979	II. 1980-
A. Living things and their environment	A. Living things and their environment
1. To guide the children to the necessity of roots, stalks, and leaves in growing plants	1. To have the children examine how nutrients are used and formed when plants grow
2. To guide them to understand the growth of plants in relation to sunshine and temperature	2. To have them observe insect growth and activity, body structure, and life cycle metamorphosis
3. To guide them to understand the differences of the state of growth and activities of insects with regard to temperature	
B. Matter and energy	B. Matter and energy
1. To guide the children to understand the quantitative limits of soluble substances in water	1. To have the children examine the state when a solid dissolves in water, and to let them understand that the dissolution of a substance varies with the water temperature
2. To guide them to understand the properties of water and air regarding changes in state and volume caused by temperature	2. To have them examine the states of air and water when heated or cooled, and let them understand the change in volume of air and water and the change of the state of water temperature
3. To guide them to understand qualitative differences in substances from their weights	3. To have them construct scales and examine their function and to let them understand that the weight of objects can be measured by scales
4. To guide them to understand properties of starch and oil	
5. To guide them to understand balancing scales	

TABLE 1.10 (continued)
Teaching contents of the fourth grade in Japan

B. Matter and energy	B. Matter and energy
6. To guide them to understand the rate of current flow in miniature bulbs and conducting wires	4. To have them examine the brightness of a miniature bulb in the various types of circuits using a miniature bulb and dry batteries
7. To guide them to understand focussing sunlight using a magnifying glass	
C. The Earth and universe	C. The Earth and universe
1. To guide the children to understand that the relative positions of the stars do not change by the lapse of time	1. To have the children observe the changes in appearances and positions of the sun and the moon in the sky, and to let them understand that the movement of these two bodies is similar in a day
2. To guide them to understand the changes of the air temperature throughout a day	2. To have them observe how rainwater runs on the ground and examine the beds and banks of rivers, and understand the functions of running water
3. To guide them to understand that the state of a river beach is related to the running water	

Source: Masao Miyake, "National Science Curriculum Case Studies," unpublished paper, National Institute for Educational Research (Tokyo, 1981), p. 17.

TABLE 1.11
Major items of teaching contents in Japan

I. First Area (Physics & Chemistry)	II. Second Area (Biology & Earth Science)
A. Grade 7	A. Grade 7
1. Substance and reaction	1. Kinds of living things and their lives
2. Forces	2. Earth and universe
B. Grade 8	B. Grade 8
1. Substance and atom	1. Physical mechanisms of life
2. Electric current	2. Weather changes
C. Grade 9	C. Grade 9
1. Substance and ion	1. Relationship among living things
2. Motion and energy	2. Changes in Earth's crust
	3. Human beings and nature

Source: Masao Miyake, "National Science Curriculum Case Studies," unpublished paper, National Institute for Educational Research (Tokyo, 1981), p. 8.

as the method of instruction forced by this volume -- has led some critics to fear that the burden on students is too great. Ohashi considers the curriculum ". . . cause for the increase of students who dislike science. . . ."[45] Moreover, a national survey of practicing science teachers identified four common problems: lack of time for teachers to initiate innovations; lack of money for materials for innovations; low training or lack of "know-how"; and low affect of teacher and of student, that is, low performative zeal which could be characterized by the attitude that "the blackboard is enough, it is known and safe."[46]

One must be careful, however, not to read too much into criticisms of science teaching by Japanese practitioners. There are problems, but Japanese students do have the world's highest average level of learning in science, and they achieve it with a lower level of variation between students, which indicates that Japanese schools are treating students relatively equally.[47] There is little variation between schools due to compensatory aid from the national government,[48] and the system of planned uniformity is successful in producing students who have mastered the material and who are relatively equal in performance. Nevertheless, the Nikkyōso is concerned about the large volume of information in the curriculum,[49] and the latest revision in the course of study for science has decreased the number of topics to be covered. Proponents hope that this will result in a greater ". . . grasp of essentials in the time allowed teachers to convey them and still [allow teachers to] complete the text."[50]

Upper Secondary School Science Education

Assessing science literacy in upper secondary schools is difficult. Although required courses are few, most students take at least some elective science. Moreover, the latest curriculum revision went into effect for tenth graders in April 1982, and adequate descriptive materials were still lacking at the time of this writing. Hence, this discussion will largely follow the unrevised curriculum, which was then still in use in eleventh and twelfth grades.

There are two key differences between the old and new curricula. First, there is a reduction in the required number of credits (from 6 to 4, with the creation of integrated Science I). Second, ordinary and advanced versions of courses in physics, chemistry, biology, and earth science have been combined, with greater emphasis on basic materials. However, many schools view the Mombushō's course of study as only a minimal requirement, and each teacher or school typically has a "supplemental curriculum." Many of these curricula are eventually published in a variety of publications.[51]

Table 1.12 shows one means of assessing how much science is taken at this level. The liberal estimate, books to students, equals 1.25; typically then, students take at least one course per year, and

TABLE 1.12
Demand for science textbooks in Japana

Course	Number of Books	Ratio of II/I
Basic Science	62,869	NA
Physics I (3)	1,259,829	
Physics II (3)	238,972	.190
Chemistry I (3)	1,525,502	
Chemistry II (3)	367,043	.241
Biology I (3)	1,284,741	
Biology II (3)	255,207	.199
Earth Science I (3)	563,525	
Earth Science II (3)	33,443	.059
TOTAL	5,591,131	
Total number of students	4,479,343	
Books/student		1.248

Source: Adapted from Hideo Ohashi, "Evaluating Curriculum Change in Japan," Journal of Science Education in Japan (1980) 4:134.

aFigures are for upper secondary schools in 1979.

one student in four will take a second course per year. On average, then, eleven of the eighty required credits, or 14 percent, will be in science. Roughly one-sixth of the students take the advanced rather than the ordinary course in a subject, although this distinction is being eliminated.

Students are required to take either basic mathematics or mathematics I. The former is less advanced, and includes the following topics: sets, geometry, differential coefficients, sampling and probability, logic, vectors and matrices, the concept of linear programming, and computers and flow charts. More advanced mathematics course topics include limits, differential equations, statistical inference, and operations research.[52] These advanced mathematical concepts are then incorporated into the science courses to achieve a level of sophistication that is not achieved in U.S. science courses until college.

Physics I includes the following major topics: motion and force, energy, wave motion, and electrical fields and electrons. Both conceptual and mathematical treatment of these topics is given.[53] Chemistry I includes chemical quantities and formulas, states of matter, chemical reactions (including chemical equilibrium), and properties of matter and the periodic table.[54] The typical student will take three or four courses from Science I, physics, chemistry, biology, and earth science.[55]

Science and Teacher Training at the University Level

Enrollments in science and engineering at the university level have risen rapidly in the postwar period.[56] Scientific training at this level serves two functions: to develop scientists for industry and to prepare science teachers for the schools. Technical colleges (tenth through thirteenth grades), with an enrollment of 46,348 in 1980, graduate mainly practically trained engineers and technicians.[57] Another 21,150 junior college students study engineering. The number of university students in engineering, a more theoretical course of study, was 339,760 in 1979, or 19.7 percent of the total university enrollment; 1.2 percent of engineering majors were women, while 3.5 percent of the graduates entering employment were women.[58] Science and mathematics majors were a smaller fraction of all majors, 3.1 percent, or 54,578 in 1979, 18 percent of whom were women.[59]

Teachers are trained in both junior colleges and universities, although most are trained in the national university system.[60] Two types of teacher certificates are given in Japan (see Table 1.13 for the requirements of first- and second-class teacher certificates). Prospective teachers must first pass an appointment examination, which is conducted by the prefectural board of education. Teachers are then issued a certificate that is valid for life in all prefectures.[61]

There has been an ongoing effort, for several reasons, to

TABLE 1.13
Minimum requirements for teacher certificates in Japan

Type of Certificate		Basic Qualifications	Minimum # of Credits to be Earned, by Subject: Teaching Subjects	Professional Subjects[b]	Special Educ. Related Subjts.
Elementary school teacher	1st class regular	Bachelor's degree	16	32	--
	2nd class regular	At least 62 credits (incl. 2 phys. ed.) after 2 yrs. at university or jr. college	8	22	--
Lower secondary school teacher	1st class regular	Bachelor's degree	40 (A)[a] 32 (B)	14	--
	2nd class regular	At least 62 credits (incl. 2 phys. ed.) after 2 yrs. at university or jr. college	20 (A) 16 (B)	10	--
Upper secondary school teacher	1st class regular	Master's degree or at least 30 credits after 1 yr. study at advanced course designated by the Minister or its equivalent	62 (A) 52 (B)	14	--
	2nd class regular	Bachelor's degree	40 (A) 32 (B)	14	--

Teacher of special school	1st class regular	Regular certificate of kindergarten, elem., lower or upper second.	--	--	20
	2nd class regular	Same as 1st class reg.	--	--	10
Kinder-garten teacher	1st class regular	Bachelor's degree	16	28	--
	2nd class regular	At least 62 credits (incl. 2 phys. ed.) after 2 yrs. at university or jr. college	8	18	--

Source: National Institute for Educational Research, Basic Facts and Figures About the Educational System in Japan (Tokyo, March 1982), p. 23.

[a]"A" requirements are for lower secondary teachers of social studies, science, industrial arts, homemaking, and vocational subjects, and for upper secondary teachers of social studies, science, home economics, agriculture, industry, business, fishing, and mercantile marine. "B" requirements are for lower secondary teachers of Japanese language, mathematics, music, fine arts, health and physical education, health, vocational guidance, foreign languages and religious education, and for upper secondary teachers of Japanese language, mathematics, music, fine arts, arts and crafts, calligraphy, health and physical education, health, nursing, vocational guidance, foreign languages, and religious education.

[b]Up to one-half of the total minimum number of credits for professional subjects may be substituted for credits earned in teaching subjects, for lower secondary teachers of music and fine arts, as well as for upper secondary teachers of mathematics, science, music, fine arts, arts and crafts, calligraphy, agriculture, industry, business, fishery, and mercantile marine.

recruit and train excellent new science teachers, continuing the program begun under the old Science Education Promotion Law.[62] First, there has been concern that many of the science teachers hired immediately after World War II had received a lower level of training.[63] Second, the period of rapid industrial expansion in Japan -- when many science teachers were drawn away from teaching -- negatively affected the quality of science teaching.[64] Third, the percentage of science teachers in Japan who are older than 27 is quite large; in the first IEA study, 80 percent of primary school teachers and 89 percent of junior high school teachers were over 27.[65] Laws to promote science education and increase salaries have helped to redress the problem, as has Japan's depressed economy, which in recent years has encouraged "the better students to be attracted to the teaching profession."[66]

The ability of the prefectures to recruit good teachers is affected by considerations of both salary and status. Differences in fringe benefits, job security, and a variety of other allowances and compensation programs make it difficult to compare teacher salaries in Japan to those in the United States. But generally, Japanese teacher salaries are probably higher. In addition, the Japanese offer special incentives to encourage high-quality applicants, including a thrice-yearly bonus for all teachers (bonuses usually total about five times the monthly salary; see Table 1.14). Length of service, level of school, and type of teaching certificate all determine both salary and allowance. Salary scales for prefectural, municipal, and often private school teachers are based on those for national school teachers and are revised yearly for cost of living.[67] Retirement benefits, however, are generally less favorable than those in the United States, while the inexpensive national health insurance is available to all Japanese.

More directly comparable than salaries is the prestige of teachers and professors relative to other professions. Although the whole status range has narrowed in the postwar era due in part to the teaching of egalitarian values by the Nikkyōso,[68] Japanese teachers enjoy a much higher status than their counterparts in the United States. This is reflected in speech, where they are accorded linguistic deference, and is measurable on prestige scales. For example, in 1975, the prestige ranking of university professors and physicians was an identical 83, while the ranking for teachers and civil engineers was 63.[69] Comparable figures for the United States ranked physicians above professors (92 versus 84 on the Duncan SEI, and 99 versus 96 on the census ranking), and school-teachers were ranked substantially below civil and mechanical engineers (72 versus 84 on the Duncan SEI, and 89 versus 96 on the census ranking).[70]

As one might expect from the higher status accorded teachers in Japan, the profession is male-dominated. In 1979, 49 percent of primary school and 90 percent of junior high school teachers were male.[71] This pattern is also reflected in the universities where, in 1979, 94 percent of students in the science section of the general education curriculum were male.[72] These figures further

TABLE 1.14
Average monthly starting salary[a] (in yen) of Japanese school-teachers, by school level and educational attainment

Educational Attainment	Kindergarten Teachers	Elem. & Secondary School Teachers[b]	Technical College Teachers	University Teachers
Junior college	135,200	138,900	136,700	131,700
Bachelor's course	156,100	160,300	161,300	161,300
Master's course	182,700	187,600	191,400	191,000
Doctor's course	218,000	223,800	231,000	231,000

Source: National Institute for Educational Research, Basic Facts and Figures about the Educational System in Japan (Tokyo, March 1982), p. 23.

[a]Includes bonus. Each figure was produced by means of the following formula: Monthly salary x 16.9/12 .
[b]Includes special allowance for teaching profession.

corroborate the pattern of inequality between the sexes described earlier.[73]

Although there is a policy in Japan to hire younger -- and presumably more up-to-date -- teachers, these teachers have a commensurate disadvantage because of their relative inexperience. In the universities, the teaching curriculum is heavily oriented toward either the subject specialization (science) or to education theory, with very little time being devoted to practice teaching. Preservice training of teachers typically includes only two weeks of practice teaching,[74] although this may be modified.[75]

New science teachers are often aided by the more senior science teachers at their school. The science teaching staff typically holds meetings at least once a week, and both the practice of lifetime employment and the cultural predisposition to defer to one's elders make the soliciting of help less onerous than it might be elsewhere.

Science teachers can also expect to receive help from one of the local science education centers. Numbering about 200, these centers provide in-service teacher training, encourage research in science education, and develop the general public's interest in science. Unfortunately, only a small fraction of practicing teachers undergo such training in any given year. According to a mid-1970s study, the largest problem in science education in the United States and Japan remains the general lack of in-service teacher training.[76]

Research on science teaching is also very active in Japan. Professional societies serve science teachers at every educational level, and other societies serve the different specialties. One can count at least twelve national organizations or societies interested in the promotion of science education in Japan,[77] and there are in addition numerous regional and prefectural associations. Each society has one or more journals for reporting advances in research on teaching methods and curriculum. In 1972, 74 percent of Japanese science teachers were members of a subject-specific association such as biology or primary school science, which met to discuss curricula, teaching procedures, and so forth.[78]

Meetings not only provide a forum for theoretical and research papers, they also provide a setting for demonstration lectures illustrating various methods of teaching.[79] According to Comber and Keeves, 90 percent of junior high school science teachers attend at least one conference every year (compared to 62 percent of teachers in the United States).[80]

In the IEA study, Japanese science teachers scored high on professionalism, reflecting the high proportion of teachers who are university-trained science specialists (93 percent) or who are both university-trained and teaching only science (81 percent). Comber and Keeves report that Japan ranked highest in this category, while the United States, by comparison, ranked sixth (with 74 and 64 percent, respectively).[81]

What is the link between the status of teachers and their greater professionalism in Japan? Both Japan and the United States face problems recruiting and training better science teachers. Japan has attempted to redress the problem by increasing salaries and improving in-service training. The effort is aided by the greater professionalism of Japanese teachers, which is both a cause and a result of their higher status relative to American teachers. Can the United States raise the status of its teachers by increasing their salaries and their degree of professionalism? Certainly, measures such as the establishment of science education centers and the fostering of active science teaching associations could help.

Nonschool Sources of Science Learning

People commonly associate school with learning, but not all learning takes place in school. The Japanese take pride in their many museums, zoos, aquaria, science education centers, and the like, but what I would like to stress here is the role of the media and the family in the process of learning science.

NHK television, the Japanese public network, has produced several progams on scientific topics for different levels of students. Some of the programs are used as supplements in school, but many are designed for audiences outside the schools. Interestingly, there is even a program for science teachers.

Perhaps the most unusual feature of nonschool science learning in Japan is the publication of a series of science magazines for grade schoolers. Called Kagaku no zasshi (Science Magazine), the magazines are published by a private company, Gakken, at the rate of one per month for each of the six primary school grades. Each issue of Kagaku no zasshi is beautifully illustrated and comes with its own apparatus kit. The magazines are autotelic, that is, they encourage children to solve most questions by themselves. (Each issue features an article for parents so they too can take part in the activity and aid their children.) Articles and exercises encourage curiosity on the part of the child, and while not used in school, the magazines do complement the Mombusho's course of study.

The Kagaku no zasshi series enjoys a large circulation (5,670,000 in 1982).[82] Over half of all households in Japan with students in grades one through six receive at least one issue of Kagaku no zasshi, and many families subscribe to more than one level. By comparison, Junior Scholastic, the only comparable magazine in the United States, has only 826,416 subscribers.[83]

The widespread distribution of Kagaku no zasshi illustrates one aspect of the role of family in the encouragement of science. More evidence on the role of the home is provided by the IEA study. Among junior high school students in Japan, the variable home circumstances -- a composite of father's occupational status, father's and mother's education, books in the home, and family size -- was found to be the most powerful predictor of science achievement in 14-year-olds. A

path analysis of the results shows a correlation of .38 and a path coefficient of .33. [84] Thus, we find that family plays a substantially larger role than type of school, learning conditions, teacher characteristics, or kindred variables in either the between-student analysis[85] or the between-school analysis.[86] The study found that "the most powerful factor from among learning conditions was hours spent on homework per week, which had a path coefficient of .12 to Achievement in Science."[87] Yet here again, home circumstances are salient, with a path of .22 to homework. Furthermore, home encouragement of learning, and of studying science in particular, an attitude not measured by home circumstances, must logically be a major additional reason for studying.

Among advanced primary school students, a truncated home circumstances variable omitting father's and mother's education was again very potent, having a correlation of .33 with science achievement.[88] Comparing junior high school students with 10-year-olds, we find that father's status declines somewhat in importance, while books in the home and the composite home circumstances variable increase in importance. This argues for the rising importance of processes in the home as factors in science learning.

Further evidence is found in the large negative correlation of family size and science achievement (-.21). [89] If family background characteristics are determinative, the continued role of family size would be less easily explained (10-year-olds in Japan and the United States were -.20 and -.18, respectively; 14-year-olds were -.21 and -.12, respectively). Large family size diminishes the amount of individual attention that parents can give their children; thus, activities in the home rather than family background are important. I have argued elsewhere that family status does not occupy the central role in learning; rather, it is home commitment to learning science that is crucial, and it is processes within the home that mediate the influence of parental status upon child learning.[90] Family members not only teach science, they also encourage its learning and act as role models when they are interested in learning science themselves. In my own studies, I have found a strong association between the perceived interest of parents and siblings and the child's interest in and liking of science, both in the United States and Japan.[91] Home encouragement for and liking of science influences the child's liking of science, which in turn is strongly associated with science learning. This is particularly true in Japan, because a child's interest in science and his or her achievement is more closely associated than in any other country.[92]

While father's status is a somewhat more important correlate for American junior high students (.31 versus .24), books in the home and family size are more important in Japan (United States versus Japan, .25 versus .32; -.12 versus -.21). [93] Masao Miyake, chief of the science education section at the National Institute for Educational Research, feels that it is likely that the influence of home encouragement on learning science will rise in importance relative to the influence of family income in the next IEA study.[94]

The influence of the family is in part felt through the mother, and fostering the education of her children is seen as one of her most important roles.[95] Japanese mothers tend to be actively involved; they make frequent visits to the school, and teachers solicit parental -- especially maternal -- involvement in the child's homework.[96] Both foreign experts and Japanese science educators agree on the importance of the family in education. "Parents, and especially mothers, take a great interest in how well the school prepares their students for examination . . . parents take an active role in local school activities, supporting teachers of excellence and school administrators who try to maintain quality education."[97] "Needless to say, the influence that parents have on a child is big. The influence the mother has on her child is especially so. Thus, the mother holds the key to [the] child's understanding . . . of science and technology."[98]

The link between learning and success in life is fairly clear in Japan. The student wants to learn both to please his parents and to succeed in the future. The teacher is an "ally who is trying to assist the student facing the examination."[99] The family is also part of the process of learning, which is often a cooperative effort among parents, teachers, and students. Not only does the mother play a major role, which the teacher encourages, but there is a congruity between home and school environments which fosters learning. I would argue that there is a better fit in primary school and probably in junior high between the warmth and support of the family and that of the school environment in Japan than in the United States.[100]

The net result is that Japanese students score very high (both 10- and 14-year-olds were first-ranked overall) in science learning. And because primary school students are encouraged to be creative in their science learning -- to use "science play" -- they are particularly adept cross-culturally in understanding and in higher mental processes in science (first rank), although they score lower in actual information about science (10-year-olds were fourth-ranked; 14-year-olds, second-ranked). In overall science achievement, 10-year-olds in the United States, by comparison, ranked fourth, and 14-year-olds ranked seventh, while American senior high school students were ranked fourteenth in a comparison of 18 countries.[101]

Evaluation and Application of Japanese Science Education

The quality of science education in Japan is very high. The breadth and depth of high school science and mathematics courses extend to topics that most American students do not see until college, if at all. Particularly impressive is the level of sophistication of high school science courses, which is achieved by integrating mathematics into the curriculum.

The findings of the IEA study of science education in nineteen industrial countries are perhaps the best way of addressing the quality of primary and junior high school science education. At the primary school level, the Japanese led the world. The Japanese score was 21.7; the United States, 17.7; and the mean 16.7. [102] In the junior high school sample, the Japanese were the highest in terms of coverage of test items. In terms of achievement, the Japanese score was 31.2; the United States 21.6; and the mean 22.3. [103] The United States fell further behind the mean in high school, while the Japanese did not participate at that level. From what we have seen about science education, however, it is very likely that the Japanese would have done very well at the high school level. [104]

What are the advantages and disadvantages of the Japanese educational system, and why does it work so well? Could some aspects of the Japanese system be transplanted to the United States? Are there limitations to doing this?

The success of Japanese science education is due to general characteristics of the society and the educational system, as well as to specific features of science education. Centralization of authority in the Mombushō and the heavy emphasis on entrance examinations are salient features of the educational system. Planned uniformity means that there is an economy of scale in educational research, textbook preparation, and teacher education, and there is the heightened possibility for coordination across the country and over grade levels. Students who move from one place to another have no need to fear a change in course content.

The system works because the Mombushō is a relatively effective meritocratic institution. Let alone, it might not function as well, but the countervailing force of the Nikkyōso keeps the pursuit of educational quality and equality high. The Japanese value literacy and have a lifelong commitment to learning. Democracy is another important value in Japan, as is the equitable sharing of resources.

The belief in equality of opportunity is, in my opinion, key to understanding the success of the Japanese system. Japanese society is strongly committed to achieving high levels of mass literacy in science and in general. Learning is a task set for all, not only for the elite. Japan is a country poor in all natural resources, save for its people. The Japanese believe, and their formal educational system helps realize their belief, that full and efficient use of human resources requires a demanding curriculum and a high level of learning by everyone.

To a surprising degree, there is equality of educational result in Japan. Even for women, there is equality of opportunity and considerable equality of result through high school. Equality of opportunity has been achieved not so much because of homogeneity of ethnicity or of family income, but because of the commitment of parents, the teachers' union, the government, and the society as a whole to meritocracy and economic democracy. Because of the pervasiveness of the examination system and because parents know

their children can advance if they work hard, parents and teachers strongly encourage all students to master the curriculum material, particularly in compulsory education. Thus, a demanding curriculum, along with an expectation of equal mastery of course material, produces a high level of learning across all subject areas.

At the classroom level, democratic values encourage equal mastery of material, and individual students act as tutors to help others in the cooperative task of learning. In the "do your best" ethic, competition is with oneself or with outsiders, and the classroom provides a warm, familistic environment. It is interesting that the "model" of learning emphasized to me in Japan was hard work plus time equals learning; the equivalent model in the United States would seem to be ability plus time equals learning. While it is possible that the latter is more efficient of inputs, it is less democratic and, more importantly, much less likely to achieve a high average level of literacy.

Families help to emphasize the relevance of learning to later life, while family and school seem to cooperate in the process of fostering the literacy of Japanese children. Parents and teachers are allies of the struggling exam-taker. Small families make possible large investments of parental time and money for juku and/or private tutors. Parental liking of science influences child liking of science, and affect and achievement are more closely tied in Japan than in other countries.[105] Families make possible much out-of-school science learning by Japanese children, be it through books and magazines in the home, museum visits, television programs, or perhaps most importantly, parental models -- home commitment to learning. Japanese adults see themselves as living in a modern, technologically advanced age in which science literacy is necessary for life as well as for success, and their commitment to the learning of science plays a crucial role in the lives of children.

But centralization and a strict examination system also have disadvantages. Large systems tend to be rigid, and the Mombushō can be inflexible. There is some possibility, however, for local flexibility, and schools in Japan enjoy more autonomy from local pressures than do those in the United States. In addition, the Mombushō operates within a political context, and the ongoing critique of the system from the Nikkyōso helps build in flexibility.

While the examination system has the advantage of providing motivation for study, it also encourages rote learning. In the Japanese curriculum, there is a shift -- brought on by pressures to pass upcoming college entrance exams -- from the hands-on, intuitive approach of primary school to rote memorization of textual materials, a process which makes some students bored with learning.[106] The fourth curriculum revision has reduced the amount of material to be learned, and there has been an upward creep of intuitive and problem-solving orientations within the curriculum. Nevertheless, the examination system takes a large toll on the lives of adolescents, and their relief at college entrance helps to explain why education at the university level is not nearly as rigorous as

at other levels.

In terms of science, Japanese students are exposed to scientific concepts from the beginning of their school careers. Not only is there science in primary schools, where observation and manipulation are emphasized, but science continues to be a larger proportion of the curriculum throughout compulsory education and high school than in the United States. The quantity of time is one reason for success. In addition, science and mathematics are well integrated. Science teachers are professional, well trained, and use up-to-date teaching methods. But perhaps most importantly, science is seen as relevant and is highly valued in this optimistic and growing society. An elite view of science is deemphasized; there is a demanding curriculum which all students are expected to master. Graduates achieve high levels of scientific literacy, and the mass media, pitched to this public, continues to expand its literacy. Parents help educate and encourage their children in science, and the Japanese citizen is encouraged to keep abreast of new developments in science, producing a citizenry able to make informed judgments on scientifically relevant issues.

The ability of the Japanese government to implement decisions quickly and efficiently has been the cause of both envy and derision in the United States. While centralization of authority accounts for part of their success, a widespread consensus on goals is fundamental. In large measure, this consensus reflects the scientific literacy of the population. Many problems confronting post-industrial societies are technological, and the ability of the Japanese citizenry to understand these problems facilitates rapid formation of a consensus.

Science education in Japan is not without its problems. Recently, there has been a teacher shortage, and many of the older teachers, hired soon after World War II, are badly underqualified by today's standards. New teachers, however, tend at first to be more oriented to theory and to their own field of specialization. The relatively small amount of student-teaching experience also diminishes the effectiveness of new science teachers.

What can be transplanted to the United States, and what are the limits to adoption? Relative to the Japanese, Americans are highly distrustful of centralization and frequently try to sabotage it. There is also no widespread respect for learning; Americans are far more apt to be anti-intellectual, and in this country, we have encouraged an elitist view of science. Moreover, in my observations of high schools and universities, I have found many teachers of science who are proud of the difficulty of their subject and who are little concerned with the adequacy of their teaching methods.

Further, there is the question of our commitment to full equality of educational opportunity. Could we institute a meritocratic examination system with financial support for all those who need it? Will the economically privileged pay so that all schools are equally good at the compulsory levels, or allow merit to

be the sole judge of entrance? Are family and youth motivated to support such a massive involvement of time and energy?

Science education centers would seem to be a worthy, if small, adoption. Kagaku no zasshi, the science magazine for primary school students, would be a particularly useful adoption if it served to strengthen the link between family, student, and classroom; for as we have seen, when family and classroom reinforce one another, more learning takes place. The United States could learn much from Japanese primary education, which is highly successful in imbuing an intuitive grasp and reservoir of interest in science. While this interest may decline due to a natural specialization of interest, the Japanese primary school experience lays the base for a scientifically literate populace.[107]

Equality of opportunity has encouraged a higher level of learning in Japan. Because it is combined with measures that encourage or ensure mastery of the subject, such as a demanding curriculum and examinations, the outcome is equal mastery. For science, this means high science literacy for all. American higher education is comparatively successful, and American scientists pride themselves upon the image of American science. Perhaps these feelings of pride in the higher reaches of science can be used to strengthen the call for a stronger mass base of science literacy. If the base is not widened in the United States, it is open to question whether American science or American society can successfully withstand the challenge from abroad.

NOTES

1. Mombushō, Mombushō (1981), p. 16.

2. Ibid. pp. 15, 18.

3. Ibid., p. 16. Last figure from Mombushō, Mobutōkeiyōran (1979), p. 72.

4. Mombushō, Education in Japan (1978), p. 11; Mombushō, p. 88.

5. Mombushō, Education in Japan, p. 51.

6. Figures for 1980 are from Mombushō, Mombushō, pp. 8, 84-85. Figures for 1981 are from the National Institute for Educational Research (NIER), Basic Facts and Figures about the Educational System in Japan (Tokyo: March 1982), p. 33.

7. S. Okuda, Lecture, Japan Foundation, July 1982.

8. William K. Cummings, Education and Equality in Japan (Princeton, N.J.: Princeton University Press, 1980), p. 8.

9. Ibid.

10. Kay Michael Troost, "Educational Equality of Opportunity in Japan: Family Background and Gender," unpublished paper, NIER (July 1982).

11. Mombushō, Education in Japan, p. 102.

12. Mombushō, Mombushō, pp. 43, 88.

13. Cummings, Education and Equality, p. 75.

14. "Teachers shall fight for equality of opportunity in education." This is the first item in the 1952 Nikkyōso "Code of Ethics for Teachers." See Cummings, Education and Equality, p. 38.

15. For an extended treatment from a pro-union source, see Cummings, Education and Equality, especially chapter 3.

16. Christopher Jencks, Inequality (New York: Basic, 1972) and Who Gets Ahead (New York: Basic, 1979). See also Troost, "Pathways to Learning: The Central Role of the Home Environment," Hiroshima Forum for Psychology (1980) 7:35-46. NSF Grant no. SED 7919784.

17. Thomas P. Rohlen, "The Juku Phenomenon: An Exploratory Essay," Journal of Japanese Studies (1980) 6:207-242.

18. See L. C. Comber and John Keeves, Science Education in Nineteen Countries (New York: Halsted Press, 1973). In the spring and fall of 1983, the second IEA study of science and mathematics was conducted in Japan by the National Institute for Educational Research (NIER) (Kokuritsu Kyōiku Kenkyūjo in Meguro-ku, Tokyo) under the direction of Shigeo Kojima; the mathematics study was under the direction of Toshio Sawada.

19. The twelve countries studied were Australia, Belgium, England, Finland, France, West Germany, Israel, Japan, the Netherlands, Scotland, Sweden, and the United States.

20. The nineteen countries studied were Australia, Belgium (French), Belgium (Flemish), Chile, England, West Germany, Finland, France, Hungary, India, Iran, Italy, Japan, the Netherlands, New Zealand, Scotland, Sweden, Thailand, and the United States.

21. Cummings, Education and Equality, p. 174.

22. Comber and Keeves, Science Education in Nineteen Countries, p. 258.

23. Equality and equality of opportunity are interrelated. In Japan, there is more income equality than in the United States. Using GINI coefficients where .00 indicates full income equality and 1.00 total equality, Andrea Boltho found Japan with .32 in 1965 and .28 in

1979; the United States had a score of .40 in 1964, indicating greater income equality for households in Japan than in the United States. See Boltho, Japan: An Economic Survey, 1953-1973 (New York: Oxford University Press, 1975).

24. See Troost, "Educational Equality of Opportunity in Japan," for a more extended discussion on enrollment percentages, advanced degrees, entrance examination success rates, and employability of advanced degree holders.

25. Cummings, Education and Equality, pp. 20, 169.

26. Comber and Keeves, Science Education in Nineteen Countries, p. 248. The correlation (r_{xy}) was equal to -.08, that is, boys were slightly higher in achievement; the mean for the nineteen countries was -.11.

27. Ibid., p. 258. Comber and Keeves found a correlation of -.28 between gender and cognitive achievement in science (mean rxy = -.20, U.S. = -.22, West Germany = -.30).

28. See Cummings, Education and Equality, pp. 160, 172; Thorsten Husen, International Study of Achievement in Mathematics (New York: Halsted Press, 1967), pp. 22-25, 274ff; and Comber and Keeves, Science Education in Nineteen Countries, pp. 159ff, 208, 217, 251, 261.

29. Hideo Ohasi, "Evaluating Curriculum Change in Japan," Journal of Science Education in Japan (1980) 4:136.

30. While the first exam is the same for all National Universities, the second is both university- and faculty-specific. The second exam is given on the same day by each national university so the student must assess his chances of passing before choosing whether to apply to Hiroshima, Kyoto, or Tokyo University, for example. Scores on the first exam do give some indication of the likelihood of success on the second.

31. See, for example, Christie Kiefer, "The Psychological Interdependence of Family, School, and Bureaucracy in Japan," in Takie Sugiyama Lebra and William P. Lebra, eds., Japanese Culture and Behavior (Honolulu: University of Hawaii Press, 1974), pp. 342-56, and Cummings, Education and Equality, especially chapters 5 and 7.

32. Some private schools, especially junior colleges and others of lower rank, do consider grades to varying degrees. See Mombushō, Mombushō, p. 40.

33. This is especially true in compulsory education. See also Kiefer, "Psychological Interdependence."

34. Don Spence, personal communication.

35. The Mombushō and Nikkyōso are at odds over what values

should be taught, and this has resulted in minimization of political value issues and emphasis on psychological concerns.

36. Kiefer, "Psychological Interdependence."

37. Troost, "Familial Pathways to Learning: The Influence of Parental Background, Number of Siblings, and Home Environment Upon Affect for and Achievement in Science -- A First Report." Unpublished paper, Kyoikugakabu, Hiroshima (1980).

38. For greater detail, see Shokichi Iyanaga, "Mathematical Education in Japan," Journal of Science Education in Japan (1981) 5:121-31.

39. Michinori Oki, "School Systems and Chemical Education in Japan," Journal of Science Education in Japan 3 (1979):191.

40. Personal communication, Hideo Ohashi, former director of NIER and currently director of Komaba Toho High School; Shigeo Kojima, director of the Science Education Center, NIER; Yoneji Ebitani, former dean of the Faculty of Education at Hiroshima and currently professor at Fukuyama University; and Shigekazu Takemura, professor in the Faculty of Education and Graduate Study, Hiroshima University.

See also Ohashi, "Some Problems of Science Education in Japan," unpublished paper of NIER presented at the preparatory Group Meeting of Science Education in Seoul (July 1975); Ohashi, "Evaluating Curriculum Change in Japan"; and Masao Miyake, "National Science Curriculum Case Studies," unpublished paper, National Institute for Educational Research (Tokyo, 1981).

41. Ohashi, "Evaluating Curriculum Change in Time," p. 134. See also Ronald S. Anderson, Education in Japan (Washington, D.C.: Government Printing Office, 1975), pp. 150-51.

42. Edward Bradford Titchener, Systematic Psychology: Prolegomena, Rand B. Evans and Robert B. MacLeod, eds., (Ithaca, N.Y.: Cornell University Press, 1972).

43. Ohashi, "Some Problems of Science Education in Japan," p. 3.

44. Masao Miyake, "National Science Curriculum Case Studies," pp. 12, 14.

45. Ohashi, "Some Problems of Science Education in Japan," p. 4.

46. Personal communication with N. Ohsumi, a staff member in the audiovisual aids for science at the Science Education Center of NIER; see also Ohsumi, "Development of Teaching Materials and Instruments for Science Education at Elementary School Level in Japan," unpublished paper, NIER, Country Report for Regional Workshop for the Compilation of an Inventory of Appropriate Aids for Science Teaching (Tokyo, November 1981), p. 3.

47. Cummings, Education and Equality, pp. 160, 172ff; Comber and Keeves, Science Education in Nineteen Countries, especially p. 159ff.

48. The influence of between-school variation upon student science achievement was almost nil in the Japanes IEA sample; see Comber and Keeves, Science Education in Nineteen Countries, pp. 208, 217, 251, 261.

49. Cummings, Education and Equality, pp. 155-56.

50. Ibid., p. 155.

51. Because the course of study applies uniformly throughout Japan, the formal describability of Japanese education exceeds that of the United States where the curriculum varies from state to state and school district to school district. In Japan, only "the hidden curriculum of juku" remains informal and unregulated, while in both societies, the role of television cannot be fully assessed.

52. Mombushō, Course of Study for Upper Secondary Schools in Japan (1976), pp. 63-77.

53. Ibid., p. 83.

54. Ibid., p. 87.

55. See Thomas P. Rohlen, Japan's High Schools (Berkeley: University of California Press, 1983), p. 157, for a comparison of science and mathematics in U.S. and Japanese high schools.

56. Several universities specializing in science and technology have been established in the last decade, chief among them the new Tsukuba University. Two new universities of teacher education Jōetsu and Hyōgo, were established in 1978 (see NIER, "The New Teachers' Training Program at Hyōgo University of Teacher Education," National Institute for Educational Research, Tokyo, NIER Occasional Paper 03/82: June 1982).

A cautionary note about university-level education in Japan, including teacher education is appropriate. While in the United States, college or university days are apt to be more rigorous academically than high school or junior high, the same is not true in Japan. John Zueguer, of Worcester Polytechnic Institute, has described Japanese universities as "high entry, low exit," that is, while they are very difficult to get into, they tend to require less of their students than has been expected of them prior to entrance and less than is typical in other societies.

57. Mombushō, Mombushō, p. 15.

58. Mombushō, Mobutōkeiyōran, p. 72, 202.

59. Ibid., p. 72.

60. NIER, Basic Facts and Figures, p. 22.

61. Ibid., pp. 22-24.

62. Anderson, Education in Japan, p. 166.

63. Personal communication with Ohashi, creator and former director of the Science Education Center at NIER.

64. Oki, "School Systems and Chemical Education in Japan," pp. 180-81.

65. Comber and Keeves, Science Education in Nineteen Countries, pp. 81, 82.

66. Ibid., p. 181.

67. NIER, Basic Facts and Figures, p. 24.

68. Cummings, Education and Equality, especially chapters 3 and 9.

69. Ibid., p. 255. See also Delbert Miller, Handbook of Research Design and Social Measurement (New York: Longman, 1977), pp. 217-18.

70. Miller, Handbook.

71. Comber and Keeves, Science Education in Nineteen Countries, pp. 81, 82.

72. Statistics Bureau, Prime Minister's Office, Japan Statistical Yearbook (Tokyo: Nihon Statistical Association, 1981), p. 612.

73. Even in the field of elementary education discrimination in administrative positions occurs in Japan. In 1971, only 2.7 percent of head teachers and only 1.1 percent of principals were women. Fujin ni kansuru shomondai chosa kaigi, Gendai Nihon Josei no Ishiki to kodo (Tokyo: Okurasho Insatsu-kyoku, 1974), p. 181. See also Samuel Coleman, Family Planning in Japanese Society: Traditional Birth Control in a Modern Urban Culture (Princeton, N.J.: Princeton University Press, 1983).

74. Miyake, "National Science Curriculum Case Studies," p. 9.

75. NIER, "The New Teachers' Training Program at Hyōgo University," pp. 1-2, 5ff.

76. Herbert Their, "In-Service Training of Elementary School Science Teachers: A 1976 United States-Japan Seminar," Science Education 60 (1976):551ff.

77. Ohashi, "Some Problems of Science Education in Japan," p. 8.

78. Comber and Keeves, Science Education in Nineteen Countries, pp. 82-83. For additional information on science education and professional societies, see The Journal of Science Education in Japan, one issue of which is published each year in English (in 1982, issue 2, formerly issue 4). English language materials are becoming increasingly common with the internationalization of Japan. Indeed, in one of my site visits to education classes at a National University, I found students using some English textbooks from America. This is possible because English is one of four required areas on university entrance examinations.

79. I witnessed an excellent demonstration illustrating the inquiry method by Satoshi Itagaki, who teaches science at the primary school attached to Tsukuba University, the premier primary school for science in Japan. Itagaki was president of the Primary School Teachers Association in 1981-82.

80. Comber and Keeves, Science Education in Nineteen Countries, pp. 82-83.

81. Ibid.

82. For example, in March 1982, the publisher gave the monthly circulation of Gakken's Kagaku no zasshi as 980,000 copies per month for the first grade, 990,000 for the second grade, 970,000 for the third grade, 940,000 for the fourth grade, 900,000 for the fifth grade, and 890,000 for the sixth grade. The magazine is published twelve times a year for each grade.

83. Circulation for other science magazines in the United States is also low. For example, Popular Science has an average circulation of 1,803,309; Science 81, 699,633; Discover, 750,545; and Scientific American, 713,000. (Circulation figures for Scientific American from the 1982 World Almanac, p. 428; all others are from the World Almanac, p. 430.)

84. Comber and Keeves, Science Education in Nineteen Countries, pp. 281-82.

85. Ibid., p. 261.

86. Ibid., p. 217.

87. Ibid., p. 283.

88. Ibid., p. 245.

89. Ibid., p. 258.

90. Troost, "Pathways to Learning" and "Familial Pathways to Learning."

91. Troost, "Science and Peace Education and the Home Environment," unpublished report, Shudo University, Hiroshima (1983).

92. Comber and Keeves, Science Education in Nineteen Countries, p. 259 (r = .49).

93. Ibid., p. 258.

94. Data for the second study were to be collected in May and August 1983.

95. Fukaya Masashi, "Socialization and Sex Roles of Housewives," Merry I. White and Barbara Molony, eds., Proceedings of the Tokyo Symposium on Women (Tokyo: International Group for the Study of Women, 1979), pp. 133-49.

96. The visits serve to dramatize the learning situation of the school. One school official apologized that a planned parent meeting would not be available in the next month; school photo book dates suggest 3 to 4 visits per year. One Mombushō official suggested that family members might visit the school between 3 and 4 times up to as many as 6 or more times per year; Cummings (Education and Equality, p. 141) reports monthly visits. Specific days are set aside for mothers and fathers, with fathers coming in on a Sunday and Monday becoming a holiday. In some districts such as Mitaka, a suburban town outside of Tokyo where the teachers and city government are socialist and where teachers take education particularly seriously, these visits can be as frequent as one or two weeks. Notes between teacher and mother are also used to communicate about progress or about what the child did as homework. In special circumstances, this can become a daily correspondence. There are also weekly forms, as well as summer vacation forms, for the parent to fill out regarding teeth brushing, chores around the house, and hours spent watching TV, playing with friends, or doing homework. Two Japanese friends told me they found these forms invasive rather than an expression of interest; they filled them out as they thought was expected so that their children would not be viewed as deviant and the parents scolded by the teacher for not being concerned about their child's welfare.

97. Ezra Vogel, Japan as Number One (New York: Harper and Row, 1980), p. 165.

98. Ohashi, "Report on Out-of-School Science and Technology Education," unpublished paper, NIER (Tokyo, 1978), p. 1. See also Kunio Umeno, "Short Report on the Out-of-School Science Activities in Japan," unpublished paper, NIER (Tokyo, June 1981).

99. Vogel, Japan as Number One, pp. 164-65.

100. Competition for grades may emerge late in junior high school and develop in high school as students become concerned about whether or not they are members of the Japanese equivalent of the Calvinist "elect"; at lower school levels, competition is personal, and learning can be a cooperative effort of parent, teacher, and

student.

101. Comber and Keeves, Science Education in Nineteen Countries, pp. 122-24.

102. Ibid., p. 159.

103. Ibid.

104. In 1983, a second survey was conducted. It is reasonable to suppose that the Japanese will maintain their position in the lead. Whether the United States falls further behind or not will be interesting to see. The National Assessment of Educational Progress report titled "National Report Card on Education During the 1970s" (1983) showed "significant declines" in science achievement among fourth, eighth, and eleventh graders in the United States (p. 1ff).

105. Comber and Keeves, Science Education in Nineteen Countries, p. 259.

106. While many have argued that the emphasis on rote learning leaves Japanese students ill prepared for creative work or for developing their own ideas, this is perhaps more true of in-class than post-school learning, both on and off the job. People in industry are able to develop new ideas, and the wider population seems to have a lifelong commitment to learning in the creative sense. Finally, at the university level, the best students do develop their own ideas, and I think the same is probably true of students in the United States as well.

107. In most societies, there is a higher level of interest in science in primary school than there is later in life. This may be due in part to changes in teaching methods and the like, but it must also be due to what I call the natural specialization of interest; that is, given the limitations of time, there is a natural tendency for people to limit their occupational and leisure pursuits.

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Paul DeHart Hurd

2. Precollege Science Education in the People's Republic of China

INTRODUCTION

The educational system in China has been in almost constant turmoil since the establishment of the People's Republic in 1949. Chinese education responds faster to changes in the political climate than is true for most countries. It has therefore been used as the mechanism for bringing about social changes, transforming cultural beliefs, and fostering political ideologies in addition to transmitting knowledge. Traditionally, formal education in China has never been widespread but, instead, was limited to the wealthy and influential. The present constitution of the People's Republic of China states:

> Citizens have the right to education. To ensure that citizens enjoy that right, the state gradually increases the number of schools of various types and other cultural and educational institutions and popularizes education. The state pays special attention to the healthy development of young people and children.[1]

Chinese education is currently emerging from the impact of the Great Proletarian Cultural Revolution (1966-1976). During this period, the importance of formal schooling was deemphasized. The majority of schools were closed, and their facilities often destroyed. The length of schooling was shortened from twelve years to nine or ten years. The concept of academic and vocational schools was discarded in favor of a common school with a general program for all students. The examination system was eliminated. Students were encouraged to learn from peasants and workers and to disrespect teachers as intellectuals. Political pressures were used against teachers, and many were removed from the classroom and sent to work in the countryside. Teacher education programs were for the most part neglected, and peasants and workers were put in charge of administering schools and assigned as teachers. The status of teachers was placed in the "stinking ninth" of nine categories of class enemies, coming after landlords, renegades, class enemies, enemy agents, and other undesirables. These conditions are attributed to the "Gang of Four" who dominated the political scene during the Cultural Revolution.

In 1978, two national conferences were held to reconstruct the economy, revitalize education, and plan for China's modernization by the year 2000. The first gathering was the National Science Conference attended by 6,000 scientists who set goals and policies for China's "new long road" into the modern world of science and technology. Within weeks, a National Education Work Conference was held to plan ways "to improve the quality of education and raise the level of teaching in science and culture so as to serve proletarian politics better." The National Science Conference established policies for education in science with the statement: "We must pool our efforts among the cadres, the masses, and young people to instill the habit of living, studying, and applying science."[2]

These two conferences generated policies for "readjusting, restructuring, consolidating, and improving" education in the sciences, as well as for advancing science and technology. These policies were designed to reverse the anti-intellectual atmosphere that characterized the Cultural Revolution. The Ministry of Education was again placed in charge of educational planning, including school organization, curriculum, and teacher education. The charge was to improve the quality of education and raise the cultural level of China's one billion people, and also to develop an educational plan supportive of the "four modernizations" -- agriculture, industry, defense, and science and technology.

What follows is an overview of the development and progress of China's science education programs following the national science and education conferences held in 1978. Because the new science policies must change the direction of China's culture, it has been necessary for the leaders to consider how to do this not only in terms of formal schooling but also for the masses who are not in school.

The social context in which these developments are taking place is that of a Third World country. However, China is different from most Third World countries in that it has many natural resources -- water, oil, coal, minerals, fertile soils -- and it has made progress in using them effectively. China has a near balance in food needs and an increasingly higher level of health. The government is aware of its economic and other social needs, and recognizes that these are most likely to be resolved through investments in people and knowledge.

NATIONAL SCIENCE POLICY AND SCIENCE EDUCATION GOALS

The goals of science education are expected to serve the national policies for science and technology. The national goal as stated by Zhou Enlai in 1975 is "to accomplish the comprehensive modernization of agriculture, industry, national defense, and science and technology before the end of the century, so that our national economy will be advancing in the front ranks of the world."[3] This policy is summarized as the four modernizations. The implementation of this

policy is seen as a major goal for education in the sciences. In 1978, Deng Xiaoping, Vice Premier of the State Council, set the tone for reformulating the science curriculum, when he said,

> We must fill out the courses in primary and secondary schools with advanced scientific information within the capabilities of the students. Measures should be worked out to accelerate the development of modern educational media such as television and radio, which merit full attention as important channels for developing education with greater, faster, better, and more economic results. We should make an intensive study of how to organize productive labor, scientific experiments, and scientific research in a more planned way in school education so that they meet the needs of the economic plan and education plan still better.[4]

In 1978, the constitution of the People's Republic of China was rewritten and adopted. The new version specifically identifies policies for the conduct of science and education.

> Article 12. The state devotes major efforts to developing science, expands scientific research, promotes technical innovation and technical revolution, and adopts advanced techniques wherever possible in all departments of the national economy. In scientific and technical work, we must follow the practice of combining professional contingents with the masses, and combining learning from others with our own creative efforts.
>
> Article 13. The state devotes major efforts to developing education in order to raise the cultural and scientific level of the whole nation. Education must serve proletarian politics and be combined with productive labor, and must enable everyone who receives an education to develop morally, intellectually, and physically, and become a worker with both socialist consciousness and culture.5

Translating the new national science and technology goals for education into practice was the next task. It was obvious that the science program used in schools during the Cultural Revolution (1966-1976) was wholly inadequate in rationale, objectives, and subject matter. A decision was made to compile new science courses for the primary and secondary schools. These courses were to be designed to serve the four modernizations. Groups of scientists and teachers were appointed to develop new instructional goals for precollege science teaching and to compile supportive textbooks. The goals of science instruction identified by the textbook compilers to guide the preparation of materials were:

- Mastery of key concepts and basic information;
- Ability to conceptualize and make inferences;
- Development of systematic and logical methods for analysis and synthesis in solving problems;

- Appreciation of the importance of physical models in thinking;
- Facilitation of the student's ability to apply knowledge to practical problems, especially in agriculture and production;
- Appreciation of the evolution of science concepts to foster a dialectical-materialistic point of view and way of thinking;
- Development of skills in experimental procedures and in the use of scientific instruments.

In contrast with science education policies characteristic of the Cultural Revolution, the new science program was viewed as one emphasizing basic theories and concepts and stressing logical and abstract thinking. Problem solving, conceptualizing, and applying knowledge to production were to be stressed. The modern courses were also to stress the development of a dialectical-materialistic world view, a Chinese version of scientific methodology.

New science curricula (textbooks) were compiled to reflect the new aims of national science and technology policies. A college entrance examination was developed which in successive years has placed increasing emphasis on logical thinking and the ability to apply knowledge.

THE SCHOOL SYSTEM AND ENROLLMENTS

The "official" organization for the full-time, 10-year school system in China is shown in Figure 2.1. The precollege years consist of a 5-year primary school and a 5-year secondary school. The secondary school has a lower school of 3 years (junior secondary) and an upper division of 2 years. There is great diversity in school systems: in rural areas, an 8-grade system is common; in the cities, the 1981 plan is to convert to a 12-year school organization.

Schools are designated as full-time attendance and spare-time or work/study schools. The latter are more common in rural areas than in the cities. Nursery schools for children over 3 months of age may precede the 4-year kindergarten. Nursery and kindergarten schools are not common in the countryside; factory-run schools and special school programs in off-seasons are.

Schools are classified as ordinary and keypoint (key), with the key schools being designed for the very bright, gifted, or talented students. These schools have the best prepared teachers, well-equipped science facilities, financial resources not available in other schools, and options to deviate from the national uniform curriculum. The Chinese believe that since it is not possible at this stage of their social development to educate all children well, they should invest in the human resources most likely to bring the greatest returns for achieving modernization and social ideals. Ordinary schools follow the uniform science curriculum and do the best they can

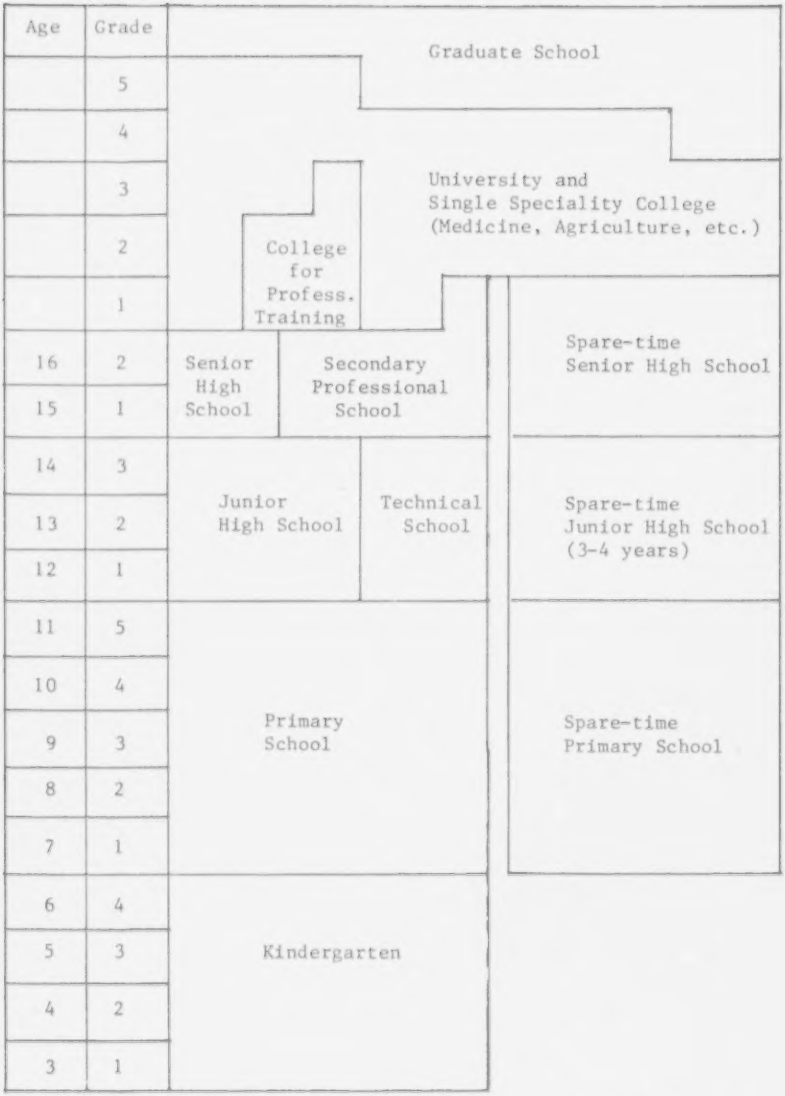

Figure 2.1 School system in the People's Republic of China

Note: Primary school teachers are trained in technical schools; secondary school teachers are trained in colleges for professional training.

with the students they have and resources available. Key classes and the separation of students into ability groups are sometimes found in ordinary schools.

The principal types of secondary schools are the general or ordinary and the vocational/technical. Of the students who graduate from a lower secondary school, less than 10 percent choose vocational/technical schools at the next level. The Chinese consider this situation to be the greatest weakness in their educational system, since they have a great need for skilled technical and agricultural workers and the school system is not producing them. Of the well-educated, by Chinese standards, senior middle school graduates, less than 5 percent are able to enter a college or university; the rest graduate without work skills and have great difficulty finding employment.

School attendance is compulsory through the fifth grade, and 95 percent of all school-age children enter school at grade one. In the cities, 30 percent of these children have attended kindergarten, and a smaller group, 20 percent, in rural areas. About 85 percent of primary school graduates enter junior high school. About 35 percent of junior high school graduates enter senior high school, and of this number, only half graduate. Though exact figures are not available, it does appear that, of the children entering grade one, no more than 20 percent will complete grade ten.

In 1980, 11.5 million children attended kindergarten, 146.2 million were enrolled in primary school, 55.0 million attended regular junior or senior high school, and 4.1 million were enrolled in a vocational secondary school. Enrollment in China's colleges and universities was 1.1 million with 350,000 graduating; new admissions for the following year were 281,000 students. In 1980, there was a total of 241 million students attending primary and secondary schools. In 1980, the faculty in schools of all levels and types numbered 11.5 million, of which only 9.3 million were full-time. Thus, there is a serious shortage of qualified teachers at all levels and especially in the physical sciences.

China's school system is the largest in the world in terms of enrollment. Compared with prerevolutionary times, there have been tremendous gains in the percentage of students attending school at every educational level. The least growth has been in higher education, but this situation is being corrected as rapidly as economic conditions permit.

SCIENCE TEACHERS AND THEIR TRAINING

China has a serious problem securing qualified teachers, and the problem is likely to continue. In 1981, the number of teachers employed was 6 million in secondary schools, 5.5 million in primary schools, and 410,000 in kindergartens. There are 300 million children of school age, 3 to 16 years old.

During the Cultural Revolution (1966-1976), few teachers were trained, and many left teaching never to return because of the abuse and disrespect that was heaped on them. To combat these attitudes, the new government mounted a vigorous campaign to raise their social level and instill respect for the important work teachers perform. At the National Education Work Conference in 1978, this policy was made clear:

> Teachers hold the key to a school's success in training qualified personnel for the proletariat, i.e., training workers with both socialist consciousness and culture. . . . We must raise the political and social status of the people's teachers. . . . We should commend and reward outstanding educational workers with wide publicity. . . . It is necessary to study the wage scale of teachers and, first of all, that of primary and secondary school teachers.[6]

In the cities, teachers are better respected than in years past, but many peasants continue to view teachers as intellectuals who cannot be trusted politically. Teachers' salaries remain low, even by Chinese standards, about $75 per month. Proven teachers of outstanding ability are publicly recognized and given prizes. Sometimes a monthly bonus of $15 is awarded, which once received, continues throughout the teacher's career.

The adoption of the four modernizations -- agriculture, industry, defense, and science and technology -- as national goals placed a great responsibility on science teachers. The Chinese hope to achieve a level of scientific and technological sophistication equal to that of developed nations by the year 2000, and precollege science teachers are expected to popularize science, motivate students to "love science," and educate students in twentieth century science. The new (1979) unified science courses for primary and secondary schools require teachers to have a much greater understanding of science, although the number of secondary school science teachers with proper training probably does not exceed 10 to 15 percent.

Science teacher education programs in teachers' colleges and teacher institutes are geared to what teachers are expected to teach. About 90 percent of the coursework is in a science department. Here, basic courses closely match sections found in the national unified textbook which the prospective teacher will ultimately use. Science textbooks for colleges are written specifically for teacher education programs, and when the series is completed, there will be a uniform curriculum for science teachers in various specialties throughout China. Part of a teacher's pedagogic training is a systematic analysis of the secondary school textbook he or she will ultimately use. This approach provides perspective on career tasks as well as relevance for the science courses studied.

A science methods course is taught in each science department by a faculty member who has had secondary school experience. This course includes preparing laboratory materials, giving laboratory

demonstrations, making charts, and for biology teachers, the collecting and preserving of specimens. A parallel course in pedagogy is taught in the education department. Topics emphasized in this course include the relationship between education, politics, and economics; the purpose of education and its relationship to economic development; the relationship between education and the physical and mental development of children; teaching processes, principles, methods, and styles; curriculum and teaching materials, including audio-visual; principles and methods of aesthetic education; principles and methods of ideological education; productive labor; physical education and hygiene; and the socialist school system and school administration.7 In addition, science teachers take courses in psychology, Chinese language, English, politics, history of Chinese education, and dialectical materialism; students have little opportunity to take elective subjects in the teacher education curriculum. Also, while in college a student is required to do a month of productive work each year. Attempts are made to relate the work experience to the student's teaching specialty--for example, a chemistry major will be sent to work in a chemical factory.

Teacher education students observe but do not participate in science classes in schools. Instead, students write a critical report of their observations, noting strengths and weaknesses.

Typically, in the first year of college, the student will teach in a nearby school for a period of six weeks or more. The student teacher is observed daily by faculty members from the appropriate academic department and from the college of education. The science observer is interested in an accurate interpretation of the subject matter, while the education observer judges instructional strategies.

All teachers are expected to play a critical role in "raising the level of socialist consciousness and commitment" in the children they teach. Every teacher has a responsibility to help students to develop mentally, morally, and physically; to acquire good attitudes and habits toward work and labor; and to recognize their importance for production. Science teachers have a special obligation to demonstrate the importance of their subject for achieving the four modernizations. Science teachers are also expected to help raise the cultural level of all people in science and technology -- the Chinese interpretation of scientific and technological literacy.

About half of the upper secondary school science teachers meet the standards of a college education, although less than 30 percent hold a college degree. In the junior secondary school, about 10 percent of the teachers hold a college degree. A five-year goal to see all upper-middle-school science teachers qualified at the bachelor's degree level is not likely to be met by the 1983 deadline. In key secondary schools, a majority of science teachers are qualified at the degree level. Teacher education institutions are being developed as rapidly as staff needs can be met and the economy allows. There is an additional problem of getting enough good students to enter teaching as a career.

Primary school teachers are trained in normal schools or specialized secondary schools. To enter, the student must be a graduate of a lower middle or junior high school and must pass an examination on the Chinese language plus receive an appraisal of attitudes, interests, and hobbies. The training program is three years long, extending one year beyond high school. The science and mathematics courses included in the program are not considered to be of high quality. The situation is all the more serious because teachers from the fourth grade on are specialized for teaching only one subject. In rural schools, teachers are more likely to be teaching all subjects. Kindergarten teachers are trained in special schools separate from primary school teachers. As is true for the secondary schools, the best qualified teachers are used to staff the key elementary schools.

Given these problems, it does not seem possible that China will be able to train the number of new teachers of the quality it desires within the next one to two decades. The alternative is to develop extensive programs of in-service education, and this China is also doing.

THE SCIENCE CURRICULUM

In 1979, China introduced a national unified curriculum in the sciences and other school subjects. It seemed that in the long run, an up-to-date uniform school curriculum would concentrate efforts and contribute to greater progress in realizing the four modernizations. With a uniform science program, teachers could be assigned where needed without retraining. Previously, large cities and the provinces each developed their own courses of study.

Science textbooks were compiled by a committee of scientists and experienced science teachers from various grade levels. Textbooks from other Communist countries, the United States, Japan, and Western Europe were examined for subject matter, sequence of topics, and age level. Appropriateness for Chinese educational goals and national science and technology policies was carefully considered. With these criteria in mind, the Ministry of Education established specific guidelines for compiling the unified textbooks. The subject matter was to be selected for its contribution toward:

- Meeting the needs of the four modernizations and advancing the national economy;
- Integrating theory with practice;
- Developing a powerful socialist state by fostering the revolutionary movement;
- Providing a solid foundation for industrial and agricultural production;

- Reflecting achievements in modern science, especially basic theory;
- Providing a foundation for continuing the study of science and technology beyond high school;
- Challenging students, while not exceeding their cognitive capacities;
- Shaping the dialectical-materialistic world view of the student.

Texts were then compiled using the experience of Chinese teachers, the advice of scientists, and insights gained from other countries. These texts were regarded as preliminary or temporary volumes that were to be rewritten within five years. The next editions were to reflect the experiences of teachers using the first edition, as well as changing national needs. In 1982, revisions of the biology, chemistry, and natural science programs began. In general, teachers found many topics to be too theoretical for the majority of students to comprehend at the grade level for which the texts were originally written.

The textbook is the course of study in a subject, and teachers are expected not to deviate from what is written. Chinese science textbooks are small (13 by 18 cm) and average 150 pages in length. The paper is newsprint. Except for a frontispiece, color is almost never used; there are, however, many line drawings. Since students must buy their own texts, prices are low, between 18 and 55 cents. The texts have a high concept density with a minimum of explanation. Teachers are expected to amplify a topic and make the learning interesting. Science teachers in key schools sometimes develop their own course of study or modify the prescribed text, but teachers in ordinary schools are not permitted to do so.

There is a modicum of flexibility in each science course, since the assigned time for teaching it is about one month less than the school year. This month may be used to teach a locally developed science module that is related to a local industry, agricultural product, or health concern. In practice, teachers have difficulty teaching the regular program in the assigned time. During the 1980s, the Chinese school system will be restructured from a ten-year to a twelve-year, full-time system, with one year being added to the primary school level and one to the secondary. No new courses will be added to the curriculum; the purpose of additional time is "to do well" with the existing courses. Key schools are allowed to develop their own science courses by making additions to the uniform course or pursuing topics in greater depth.

Incorporated in science courses are three types of supplemental learning activities: student-performed experiments, teacher lecture-demonstrations, and exercises. Students have few opportunities to perform experiments on their own because of the lack of equipment, supplies, and appropriate facilities. Within schools, a priority has

been set for the use of the limited funds available for science equipment and supplies, with physics being given first choice, followed by chemistry and biology. Even where laboratory materials are available, teachers seem hesitant to use them. Key schools are an exception -- they have first claim on all available equipment and supplies, and student experiments are common. Lecture-demonstrations by teachers are typical in most schools. Extensive use is made of charts, maps, and diagrams on the chalkboard -- the Chinese are masters in making chalk drawings. A list of exercises concludes most textbook chapters. These exercises are of two types: "word problems" in which students are to think through an investigation by applying what they have learned, and application of the student's knowledge to problems in industry, medicine, agriculture, or everyday life. Students are also encouraged to think of original ways in which to put their scientific knowledge to use. Exercises serve as a means for implementing a major goal of science teaching -- the relationship between theory and practice, and between learning and production.

The compilers of the science curriculum have been uncertain about the balance of traditional and modern concepts in science courses. There is a feeling that many of the modern concepts in molecular biology and chemical bonds, for example, now in the curriculum are too difficult for children and also are not well understood by the present corps of teachers. A major criticism of the present science curriculum by public officials is that it does not provide a proper balance of science, technology, applied science, and opportunities for developing vocational skills in upper secondary school. The curriculum is regarded as too theoretical and university-oriented to serve the attainment of the four modernizations well. The Chinese recognize the need for highly qualified researchers and technical experts, but they see an even greater need for skilled workers. To resolve the problem may mean not only a reorganization of the present science curriculum, but also a restructuring of the educational system.

COURSE OFFERINGS AND WEEKLY SCHEDULES

In China, classes are scheduled for a 6-day school week. The student class load per day is 5 subjects in grades one and two, 6 in grade three, and 8 or 9 in grades four through ten. In the primary grades, children are in class an average of 26 hours per week, in secondary schools, 28 hours. The school day begins at 8:00 and ends at 4:30 or 5:00. Class periods are 45 minutes long, and a 90-minute lunch and rest period breaks up the day. Primary school children have 8 free hours per week for extracurricular activities, secondary school students have 6 hours. The school year is 44 weeks long, or 264 days. Students have 7 weeks vacation in the summer and 2 weeks in the winter.

The Ministry of Education sets the minimum number of days per school year for instruction in a course. The amount of time varies with different subjects, but the average is 34 weeks. The remaining time may be used to extend a course, teach a locally developed module,

prepare for examinations, or carry out a project. Extending course instruction and preparing for examinations are the most common use of this time.

Students are also required to engage in productive work each year. In the primary grades, the amount of time is 2 weeks, and in the secondary school, 4 weeks. Productive work means useful work in terms of the national economy. For example, children in the primary grades may make colored chalk, construct boxes, or assemble ballpoint pens; all items are bought by the government, and the money is returned to the school to use as it sees fit. In the secondary schools, students may work in school factories, some of which manufacture science equipment, in nearby factories, on farms, or on a construction project. The purpose of the student work experience is to develop an appreciation of the importance of work and its contribution to socialist modernization. Direct experience in productive labor is one of the ways used to help students develop a work ethic and a personal sense of responsibility for helping China achieve a higher quality of life.

The weekly schedule allows the student time to study independently and to participate in extracurricular activities and sports. Science clubs and visits to science centers are popular extracurricular activities.

Course work in the various sciences extends over a period of several years (see Table 2.1). All courses in science are required of every student; there are no elective subjects in the curriculum. Should a student leave the secondary school at almost any grade, he or she will have taken courses in several sciences. In the current 10-year school curriculum there are 8768 designated hours of instruction, of which 1258 are in science and 2050 in mathematics. These figures represent the minimum number of hours prescribed for teaching a course; in practice, more hours are devoted.

In 1981, the Ministry of Education proposed adjustments in the primary and secondary school science curricula. The number of course credits was modified as follows: biology, from 5 to 6; natural science, 4 to 6; geography, 4 to 9; chemistry, 9 to 10; and physics, 16 to 14. Overall, these adjustments increase the number of credit hours in the sciences from 40 to 47. The ministry also suggested that courses in chemistry and physics be temporarily discontinued in schools where teachers in these subjects are not available. The released class time in senior high school is to be used for mathematics and languages, in the junior high school, for courses in agriculture. Additional changes in the secondary school science curriculum are expected as China moves to reduce drastically the number of general or ordinary secondary school programs and converts the curriculum to vocational/technical subjects. In Beijing, for example, it is recommended that 50 percent of ordinary secondary schools be changed to vocational/technical institutions. The 1980-81 course offerings in the sciences, their grade level, and subject matter are summarized in Appendix A.

TABLE 2.1
Course offerings for 10-year, full-time schools in the People's Republic of China (periods per week)

Subject	Primary School Grade					Junior High Grade			Senior High Grade		10-Year Total
	I	II	III	IV	V	VI	VII	VIII	IX	X	
Physical education	2	2	2	2	2	3	2	2	2	3	730
Chinese language	13	13	11	8	8	7	6	5	5	5	2482
Politics/civics	–	–	–	2	2	2	2	2	2	2	448
Natural science, general knowledge	–	–	–	2	2	–	–	–	–	–	136
Art, drawing	2	2	1	1	1	1	–	–	–	–	286
History	–	–	–	–	–	–	3	–	2	–	158
Music	2	2	2	1	1	2	–	–	–	–	352
Foreign language	–	–	4	4	4	5	4	4	3	3	1004
Mathematics	7	7	6	6	6	6	6	6	6	5	2050
Geography	–	–	–	–	–	2	2	–	–	–	128
Physiology/hygiene	–	–	–	–	–	–	2	–	–	–	64
Physics	–	–	–	–	–	–	3	3	5	5	502
Chemistry	–	–	–	–	–	–	–	3	3	3	276
Biology	–	–	–	–	–	–	–	3	–	2	152
Free hours per week	8	8	8	8	8	5	6	6	6	6	2335

Note: Total scheduled class periods over 10 years is 8768.

THE TEACHING OF SCIENCE: ASPECTS OF DIALECTICAL MATERIALISM

Science instruction in China is influenced by philosophical and psychological assumptions that harmonize with Communist political beliefs. Instructional guidelines are broadly encompassed in a theory of dialectical materialism. The theory provides a philosophical framework for the curriculum, its organization, and how it should be taught. It reflects the writings of Engels, Marx, Lenin, and Mao Zedong and their view of the role of education in bringing about a classless Communist society. However, the dialectical position includes a concept of knowledge and cognition and a "right" procedure for acquiring knowledge. While the overall aim of science education is political, the subject matter is no longer politicized as it was during the Cultural Revolution. Although science teachers are not expected to use uniform methods of instruction, they are expected to seek uniform results.

The Chinese concept of teaching and learning is somewhat different from what is accepted in the United States. Their thinking on instruction and learning is strongly influenced by the meaning they attach to dialectical materialism. The word education in a science carries a higher level of conceptualization than it does in the United States. To the Chinese, simply acquiring factual information in a course is considered barren. They refer to this kind of teaching as "stuffing the goose." Their concept of education in science is that of enlightenment. This meaning is quite like that of the Russian language where the word for education, prosvestchenye, means enlightenment. Enlightenment in science includes not only a comprehension of concepts and methods, but also an understanding of its relationship to economics, politics, work, morals, customs, and especially social change.

The goal of instruction is one of "shaping the dialectical-materialistic world view of the student." The Chinese view dialectics "to include the fundamental laws governing nature, as well as society and human thought." An education in the sciences is not only to explain the natural world, but also to help change it. Thus, the concept of change encompasses more than science; it includes actions for changing the outlook of people as well as social directions. This concept permeates all learning, the sciences as well as history and the arts. Nothing is considered static; nothing remains constant, either in science or society; everything is in a constant state of development and evolution. In human experience, change is viewed as having both qualitative and quantitative dimensions.

The Chinese notion of materialism refers to the "real world," its nature and history, which is regarded as the only true source of knowledge. Science can be learned only through study and a desire to know. In the process of learning, they proceed in an objective or scientific manner "seeking truth from facts." Their starting point in learning is with perceptual experiences based in reality. By reading, observing, and experimenting, perceptual experiences can be raised to

a level of theory or rational knowledge by thinking, inferring, and judging. The validity of rational knowledge is found in reality, practice, application, or in the transformation of nature. Roughly, the entire process corresponds to what is generally labeled scientific inquiry. To them, the dialectical method of teaching implies an objective analysis of problems. In the process of analysis, the student is encouraged to look for contradictions and to be alert for new methods of resolving the problem. In this way, the teacher hopes to instill the idea that science is not a frozen body of knowledge that is immutable, and that past explanations may not be the best explanations. Their instructional objective is to have students recognize that there are always new problems that arise in human experience, and that many of these call for innovative methods of investigation. Systematic study and learning are essential for identifying new problems and different ways for dealing with them.

In the Chinese view, dialectics requires an understanding of contradictions in developing, interpreting, and using knowledge. Contradictions may result from a discrepant event, anomalies, or a different system of explanation such as folklore versus scientific information, expert opinion versus practical results, or theory versus practice. The law of contradiction is considered a basic law of dialectics. Contradiction serves as the "motive force that impels things to move and change," giving rise to new knowledge and ideas. Change comes about in actions utilized to resolve a contradiction. In the process of resolving a contradiction, new knowledge, a new idea, or a new method for resolving a problem emerges. Success in resolving a contradiction usually leads to more contradictions.

The dialectical concept applied to a science problem requires that the problem not be viewed in isolation. Problems have interrelations and interactions, such as those of environmental management or the adoption of a new technology. In the dialectical approach, problems are examined objectively and systematically with a consideration of interactions and a "vision of the whole." This is the Chinese meaning of the scientific attitude, to which they attach major importance in teaching.

Science is taught with the expectation that what is learned will serve the interests of people, promote the socialist cause, and advance the culture. The value of learning science extends beyond knowing and reflecting of the natural world; it is basic for achieving the four modernizations and for transforming the world.

Students applying to a college or university are required to demonstrate an understanding of dialectical materialism. It is also a required course in teacher education programs. Chinese scholars recognize the criticisms that have been made of the dialectical-materialistic theory of knowledge. In 1981, the Chinese Research Society on Dialectics of Nature was founded "to research dialectics and promote the work of teaching, studying, publicizing, and popularizing the subject."

CONDITIONS OF TEACHING: THE TEACHER'S DAY

The major responsibility of teachers is to teach. They are not expected to develop curriculum materials or to participate widely in nonteachng activities. Science teachers teach only one subject, for example, biology, chemistry, or physics, and typically only one grade level. The number of class contact hours for a teacher in a 6-day week varies from 8 to 15 with an average of less than 12, about half that of a science teacher in the United States. The school day is 8 hours long with fewer hours on Saturday. Classes in science are seldom smaller than 50 students, resulting in a student load of about 300, nearly twice that of an American teacher.

Teachers are expected to prepare their classes "well and correctly." This means carefully developing and outlining lessons, choosing the best method of presentation in advance, and spending many hours reading and studying the topic to be taught. In this way, deficiencies in a teacher's education can be overcome and the subject matter kept up-to-date. Esteemed teachers are expected to help younger teachers prepare lessons and advise them on methods of presentation.

Teachers in China must carry out all the usual class-related tasks of a teacher anywhere, such as preparing and grading examinations, checking attendance (although few students are absent), setting up science demonstrations, and maintaining discipline (an easy task in Chinese schools). In addition, teachers, with the help of their better students, are expected to tutor students who are doing poorly. All teachers, from the earliest grades on, are expected to be alert for children who are especially talented or gifted. Once identified, these children will be recommended for key schools where educational opportunities are richer and teachers more experienced. In situations where this is not a possibility, teachers are obligated to give talented students special attention and to speed up their educational growth toward possible early admission to a university.

In-service education is a continuing activity for teachers. Teachers of science meet one afternoon per week for the purpose of "self-criticism." Teachers may describe their "best" lessons for comment and discussion, or they may describe their "poorest" lessons and ask for help and suggestions. Another afternoon may be spent visiting teachers of their subject in other schools. A major concern of teachers is improving their pedagogical skills, especially those for motivating students. Out of these meetings may grow written recommendations for the improvement of textbooks, which are then sent to the Minister of Education. There are professional journals in biology, physics, and chemistry that feature articles on teaching procedures, advances in science, and book lists. Correspondence courses, special radio and television courses, and a variety of short- and long-term institutes are also available. Scientists and experts in industry are encouraged to help teachers improve their knowledge of science and technology. For a few teachers, there are opportunities to attend summer science camps. It is estimated that about 20 percent of China's teachers participate in formal in-service

programs. Good teachers are publicly recognized and rewarded. The poorest of teachers -- those who show little improvement after four or five years of experience -- are assigned to nonteaching tasks in the school. Retired teachers are encouraged to visit schools and share their expertise. Some universities offer graduate training programs for teachers with three or more years of experience.

The majority of science teachers work under difficult conditions, in schools lacking equipment or satisfactory facilities for doing experiments. Although the quality of education and teaching is a subject of almost daily criticism in the press, major accomplishments have been made since the present government took over in 1949. Today, there is less illiteracy, better science instruction, and more children in schools. Science is the knowledge most essential for achieving China's modernization program, yet here teacher qualifications are the lowest in terms of modern science.

STUDENTS AND LEARNING

Chinese students are alert, attentive, and eager to learn; they do not need to be coerced. Discipline has not been a problem until recently, and then only in a few of the larger cities. The curriculum is standard for all. Students in the upper grades have some opportunity to choose between liberal arts or a science/mathematics concentration, but they cannot choose subjects. They can choose between a technical/vocational education or a college preparatory program.

The Ministry of Education has issued the following guidelines for being "a good student":

- Love the motherland and the people, care for the collective, and protect public property;
- Study diligently;
- Take part in physical training so as to keep fit and pay attention to hygiene;
- Take an active part in physical labor and be thrifty and simple in daily life;
- Observe discipline and public order;
- Respect teachers, maintain close ties with fellow schoolmates, and be polite to others;
- Be modest and honest and be ready to correct mistakes.8

This list of rules is not unique; that they are generally observed is. These rules support the communist aim of education, which is to help students develop morally, intellectually, and physically.

Examinations play an important part in schooling, since they are used to determine whether a student is qualified to move on to a higher level of study. Examinations are required for entrance into primary school, junior high school, senior secondary school, and college. Subject examinations are given at the close of each term; the most comprehensive test is given at the close of the school year. Two weeks or more are provided for students "to consolidate their learning" for the year-end examinations. Tests failed may be repeated two or three times following tutoring. If the student still fails, he or she may be allowed to continue in the course or advance into the next grade level depending on his or her overall grade performance in other courses. Failures in three or more courses mean the student must repeat all courses of that grade level the next year. Chinese teachers are oriented to having all students succeed in learning and "make progress."

Chinese teachers and students do not mix the way they do in American secondary schools. Each respects the other and recognizes their separate tasks: teachers are there to teach and students to learn. The common objective is to recognize that everyone's knowledge is important for achieving socialist modernization and for fostering production and economic development. For one student not to learn is considered damaging to the welfare of everyone.

INFORMAL SCIENCE EDUCATION

Access to formal schooling is limited by the size of the Chinese population, the economic restraints, and the short supply of qualified teachers and educational facilities. Yet, mass education must be achieved if the four modernizations are to be realized by the year 2000. Consequently, a variety of informal educational programs have been devised. These programs take place outside of institutionalized school settings -- in the home, factory, farm, mine, community library, or on the hillside -- and require little financing. Some are designed to teach specific skills, such as machine operations or farming practices. Others are planned more broadly to develop "a great force of people armed with scientific and technological knowledge." It is also hoped that these programs will generate a spirit and enthusiasm for "learning as long as one lives," to help China meet its ever-changing needs.

"Achievement through self-study" is a national slogan. China has been offering self-study television courses in physics, chemistry, mathematics, and foreign languages (usually English) since 1960. Radio courses in these and technical subjects are also available. About half of the television and radio airtime in China is directed toward advancing the educational level of viewers. Recent refinements in TV self-study education include specially written textbooks to accompany programs, repetition of programs for review, student and teacher volunteers who act as "guides," and supplemental lectures by college faculty members. To encourage self-study, public libraries are being expanded and how-to-study books are being added. Newspapers and magazines publish columns on "Guidance for Self-Study" or "The

Friend of Self-Taught Youth."

By passing the appropriate examination, self-taught students can receive a certificate of achievement which may then qualify them to take the university admissions examination. Typically, about half of the students pass the achievement examinations and a smaller percentage pass the university entrance examination. Ambitious youths may also enroll in the TV University, China's largest higher education institution.

The drive to raise the educational level of all people has resulted in a variety of educational options. Night classes are taught by "experts" in factories and on farms to upgrade skills and production efficiency. Part-work study schools allow students to earn work points for the time they spend in schools. Factory-run schools give instruction and apprentice training. Courses for peasants in agriculture and farm management are offered during slack seasons. College and university scientists and technical persons travel to communes to lecture on science and engineering topics. Correspondence courses are on the increase, but are limited by the number of qualified persons who can answer student questions and score examinations. Commune-run schools seek to combine education with productive labor. Door-to-door teaching groups make it possible for housewives to extend their education. Courses are given in health, sanitation, child care, birth control, and other topics.

The extent of informal education is difficult to determine, as is the variety of programs. In 1980, 35 million adults were students in some type of spare-time school program.9 People attending study classes conducted at the Youth Palace in Shanghai in 1980 totaled 1.2 million, and the TV University had an enrollment of 324,000. Over 300,000 copies of teaching materials for the agrotechnology courses offered by the Central Broadcast Agricultural School were promptly sold out.10 Educational leaders in China today believe that more effort should be given to expanding self-study programs and less to formal schooling, particularly at the upper secondary school level. The rationale is that at this time informal education programs are more effective in producing skilled and technical workers so badly needed to accelerate economic development.

THE POPULARIZATION OF SCIENCE

With the downfall of the "Gang of Four," which marked the end of the Cultural Revolution, China made nearly a 180 degree reversal in its scientific and educational policies. The new leadership in China recognized that to achieve the four modernizations rapidly, it would be necessary to "raise the scientific and cultural level of the entire nation."11 In his report to the National Science Conference in 1978, Fang Yi stated:

> We should organize popular science groups which combine the efforts of both professionals and the masses, expand the publication of popular science readers and the production of

> science and educational films, run successfully halls of science and technology, museums, exhibition centers, technique-exchange teams, and various kinds of scientific and technical clubs. The press, radio, and television should devote more space and time to the dissemination of science and technology.[12]

The task of science popularization in China is to help people appreciate the role of science and technology in socialist modernization. This will require shaping new cultural patterns as well as developing new systems for communicating science and technical information. The audience includes people of all age levels and educational backgrounds, including peasants and professionals -- a billion people.

To the Chinese, popularization is a somewhat broader term than is meant by scientific and technological literacy in the United States. Popularization includes not only an appreciation of science and technology but also their application to improve work efficiency and advance scientific research. Popularization also aims to overcome superstitious beliefs in agriculture and outmoded practices in industry. The ultimate goal of popularization is to help assure the growth of production, strengthen the economy, and attain a high-level socialist state. An immediate objective is to overcome the negative attitudes, generated during the Cultural Revolution, concerning scientists as elitist intellectuals and science as pure theory unrelated to socialist construction. Popularization programs and activities are designed to motivate young people to enter science and technical careers.

In 1979, the Ministry of Education issued a circular initiating a national campaign with "love science" as the slogan.

> Our aim is to have every boy and girl understand the goal of the four modernizations and realize the important role science plays and their own revolutionary responsibility in achieving the four modernizations.
>
> Our requirements are to have every boy and girl read science books, tell or listen to science stories, set up small scientific experiments, make small scientific items, explain natural phenomena according to science, learn about future prospects in different branches of science, and apply science for the sake of the four modernizations.[13]

To encourage popularization programs:

> The government provides funds, facilities, and equipment for the popularization of science. These include industrial and agricultural exhibition centers, national science museums, aquariums, and health education centers.[14]

To create an awareness of science and technology, slogans and posters glorifying science and learning in terms of achieving the four modernizations are posted over the entrances to schools, libraries,

Children's Palaces, and other public places. Some examples are:

- "Live science, talk science, be scientific, use science."
- "Science is the eternal spring."
- "Study well and make progress every day."
- "Strive to study basic scientific knowledge."
- "Approach militantly the year 2000."
- "Learn, learn, learn."

A massive effort to effect cultural change favorable to the development of a modern scientific and technological nation by the year 2000 was initiated following the National Science and National Education Work Conference in 1978. The following actions illustrate efforts aimed at creating an enlightened public in science and technology.

- Two to three times per week, television and radio stations carry popular programs on science, health, medicine, or technological achievements. One program is always designed for young children. These programs are in addition to regular courses in physics, chemistry, and mathematics offered by the radio and TV universities. Television programs reach an estimated 30 million people and radio, over 800 million.

- Between 1978 and 1980, 4300 popular science books were published, excluding 30,000 science fiction titles, with sales of 100 million recorded for 1980. The Life of Albert Einstein and Mechanics by Ernst Mach were best-sellers. Many popular science books are published in languages suitable for minority groups such as Uygun, Mongolian, Korean, and Tibetan.

- A national organization of popular science writers has been formed with a membership of 4000 and a publication schedule planned through 1985. The national government gives recognition and awards prizes for the best science writing each year. At a recent meeting of the association, some sixty papers were presented on ways to popularize science.

- In 1982, there were 111 popular science magazines with a circulation of 117 million. Radio has a sales record of 1.9 million copies per issue. In 1981, a Chinese edition of Scientific American became available.

- Of the 1200 professional journals, magazines, and periodicals published in China, 900 are devoted to science and technology.

- There are 105 professional societies that publish popular science materials or conduct forums for nonspecialists.

- Renmin Ribao, the Party's newspaper with a circulation of 5 million, is one of 29 major newspapers that regularly feature columns on popular science. One daily paper, Kejibao, is devoted entirely to reporting science and technology news. China Peasant, a new publication in 1981

and the first newspaper written especially for peasants, carries two pages of science and agrotechnology news in each issue. For all China's 283 daily newspapers (with a combined circulation of 65 million), achievements in science and technology constitute news worth printing.

- China has three science film studios producing close to 300 films per year to popularize science.

- The Communist Youth League sponsors a "science popularization month" for children. The objectives are to have children become familiar with the life of one scientist, read at least one science book, take part in making some product involving scientific knowledge, and develop a science hobby.

- Between 1978 and 1982, over 300 science popularization centers — museums, zoos, botanical gardens, nature reserves -- were established. In addition, some 1320 science centers were formed to give children an opportunity to develop projects, hear stories, see films, and visit working scientists and engineers. Those students who complete projects enter contests, and the winners go to the Beijing annual National Youth Scientific Exhibition. Here, projects are again judged, and the winners awarded cash prizes. Exhibits remain on display for three months to inspire other children to develop science projects and to stimulate adult interest. A National Youth Science Symposium is held in connection with the scientific exhibition. Here, papers on science and technology are presented, and teacher-made laboratory equipment and other instructional aids are on display.

- Summer science camps have been organized for students "who show excellence in science." Some of these are in the cities where students study museum exhibits; others are in the mountains or at the seashore.

- In 1981, an out-of-school National Science Coaches' Association was formed to further "interest in science and energetically cultivate youngsters' scientific qualities."

- In 3800 people's communes throughout China, associations have been formed to popularize science and technology and to assist peasants and workers in applying what has been learned. Where possible, before and after photographs are used to sway peasants from a practice based on superstition to one based on science. The slogan used is "rely on science rather than heaven."

- Youth Amateur Associations for Science and Technology are found in 1320 localities. In these groups, one can study mathematics, physics, chemistry, astronomy, geology, aeronautics, radio, navigation, and other topics.

- Recently major cities have been featuring displays of science and technology achievements in front of stores. The "street of popular science in Beijing" is lined with display cases and tables of science exhibits, and merchants along the street donate window space for additional displays. In small communities, similar displays are found in factories and commune centers.

- National contests in mathematics, chemistry, and physics are held yearly to encourage students to study well.

- Plays, and recently an opera, Second Handshake, have been written about the lives and achievements of scientists.

- Libraries are being extended, especially in rural areas, and stocked with books on science and technology, including books for self-study, a new translation of the Encyclopaedia Britannica, how-to books for improving agriculture, sanitation, care of animals, agrotechnology, and many others of a practical nature.

- Children's Palaces and Youth Guidance Centers are places where gifted students can receive additional education in science and technology and perform experiments. Students who attend these centers are expected to explain to other children what they have learned and the results of their experiments.

- Selected pictures from science textbooks can be purchased in large format to help students educate their parents in some aspect of science.

- Forums, symposia, lectures, and conferences on science and technology take place in large numbers throughout China — in factories, on the open plains of Tibet, in fields, even in homes. All scientists and technical specialists are expected to contribute some of their time to the popularization of science.

A thousand years ago, China was a world center of scientific achievement and technological advances in medicine, agriculture, astronomy, meteorology, optics, acoustics, and other endeavors. However, the Chinese did not intellectually participate in the rise of modern science based on theory and experimentation, a movement originating in Western Europe about 400 years ago. Now China wants to move from its position as a Third World country into that of a modern socialist society. China's leaders recognize that to do this they must achieve a high capacity for assimilating and utilizing scientific and technical information. The situation is especially difficult, since it is necessary to redirect a culture, largely peasant in background, to a new way of thinking about the natural world. Thus, it is necessary to find ways for achieving mass scientific and technological literacy in a comparatively short period of time. Since the majority of people are not in school, their understanding of science and technology must depend on informal and

out-of-school communication systems. This is where the greatest strides have been made in the past six years; however, school science is also given high importance for the final achievement of the four modernizations.

APPENDIX A. Science Curricula in China

PHYSICS PROGRAM

Grade seven: General Physics, 2 terms, 3 periods per week.
Grade eight: General Physics, 2 terms, 3 periods per week.
Grade nine: General Physics, 2 terms, 5 periods per week.
Grade ten: General Physics, 2 terms, 5 periods per week.
Total class periods, 502.

The four-year physics program provides for 50 student laboratory experiments and 200 lecture-demonstrations by the teacher.

The first course in physics starts in the seventh grade, where most students will be thirteen years old. The course is introduced with a discussion of "Why study physics?" and "How to study physics." The sequence of topics for the first year is measurement, weight, force, pressure of liquids and gases, buoyancy, motion and force, simple machines, work and energy, heat, change of state, molecular thermal motion (thermal energy), and the heat engine.

In the eighth grade, the first half of the course deals with electricity and includes topics on electric current and circuits, current through liquids, gases and vacuum, and electromagnetism. The remainder of the course is a study of light, with topics on reflection and refraction, and it concludes with a study of optical instruments, including the eye.

The third year of physics opens with a presentation on how to do experiments and exercises well, and stresses the importance of mastering concepts and physical laws. Topics are presented in the following sequence: forces, equilibrium and variable motion, followed by the laws of motion, circular motion, and universal gravitation, with attention to artificial earth satellites. Seven student experiments are outlined, two of which are on the use of a vernier calliper and the screwthread micrometer, one on forces at an angle, one on equilibrium, and three on motion.

In grade ten, the last year of secondary school, the order of topics is mechanical energy, momentum, mechanical vibration and waves, gas equations and the theory of gas molecular motion, internal energy and the transformation of energy and the conservation laws. Six student experiments are suggested: verifying energy conservation, elastic impact, computing the speed of a bullet with a pendulum, period of a simple pendulum, testing Boyle's law, and the gas state equations.

CHEMISTRY PROGRAM

Grades eight, nine, and ten: General Chemistry, 2 terms, 3 periods per week.
Total class periods, 276.

It is recommended that 15 percent of the total class periods over a three-year period be devoted to performing 41 specified experiments. In addition, 114 lecture-demonstrations have been developed for teachers. The compilers of the chemistry program stress that 40 percent of coursetime should emphasize basic theories; the remaining time is spent on descriptive chemistry and applications.

In the first year of chemistry, students learn about hydrogen and oxygen as atoms and the formation of molecules. This is followed by a study of solutions, halogens and alkali metals, acids, alkalis, salts, and oxides. Wherever possible, chemical information is related to chemical fertilizers, a major agricultural problem in China. Students also learn about the aims and requirements of experiments and the use of common instruments. First-year experiments consist of preparing oxygen and hydrogen gases, salt purification, crystallization, solubility, concentrations, and properties of the halogens, acids, alkalis, salts, and oxides. In the second year, the emphasis is on sulfur and sulfuric acid; mol and reaction heat, structure of matter, chemical bonds, and the periodic law of elements. These topics are followed with a study of nitrogen and carbon and their compounds. Basic chemistry concepts such as rate of reaction, equilibrium, oxidation, and reduction are woven into the study of carbon and nitrogen. Industrial applications are stressed, particularly the production of nitric acid, synthetic ammonia, and silicates. Suggested student experiments deal with properties of sulfuric acid, Avogadro's number, molar concentrations, neutralization, properties of selected elements and compounds determining molecular weight, colloids, and equilibrium.

In the third year, students are introduced to electrolytic solutions, magnesium, aluminum, transition elements, hydrocarbons and their derivatives, saccharides and protein, and the synthesis of organic high-molecular compounds. There are fifteen student experiments, including those on titration, electroplating, the properties of various organic and inorganic compounds, and the preparation of phenolic resin. Among the industrial topics dealt with in the course are electroplating, softening of water, steelmaking, utilization of coal, petroleum products, and synthetic materials.

BIOLOGY PROGRAM

Grade seven: Human Anatomy and Physiology, 2 terms, 2 periods per week.
Grade eight: General Biology, 2 terms, 3 periods per week.
Grade ten: Biology Theory, 2 terms, 2 periods per week.
Total class periods, 216.

After a general introduction to human anatomy, students study the major systems of the body including the skeletal, motor, circulatory, respiratory, digestive, excretory, nervous (sense organs), reproductive, and the metabolism of matter and energy. The hygiene and care of the organs of each system are considered. Growth and

development and the hygiene of early childhood are stressed, as are "patriotic health campaigns" and the prevention of disease. Colored charts, nearly life-size, of each system illustrated in the text can be purchased. Students use these at home to teach parents and other adults about health and hygiene.

The general biology course is essentially one term of botany and one term of zoology with an emphasis on morphology. There is a brief introduction to ecology and the evolution of living things. Laboratory experiments are essentially the reporting of observations on plants and animals. There are several laboratory sessions on the dissection of the rabbit and frog. Applied biology receives little attention except for the study of carp and China's fish resources.

The second course in biology, taught in the last year of secondary school, deals with basic concepts and theories. Major topics are the material basis of life, including cell structure and functions; metabolism; reproduction and growth; hormones; heredity and variation; the origin of life; and current achievements in molecular biology, bionics, and ecology. Only two experiments are suggested for the course, mitosis and a kernel separation of hybrid corn.

GEOGRAPHY (EARTH SCIENCE) PROGRAM

Grade six: Geography of China, 2 terms, 2 days per week.
Grade seven: World Geography, 2 terms, 2 days per week.
Total class periods, 128.

Earth science is not a separate subject in China, but is incorporated into geography courses in the junior high school and into natural science in the primary school.

Geography of China begins with a study of the earth and terrestrial globes, time zones, zones of the earth, and mapping. Next comes a consideration of landforms, climate, and an overview of the rivers of China, with special attention given to characteristics of the Yangtze and Yellow Rivers. Characteristics and topography of nineteen provinces and contrasting regions are described with reference to plant and animal ecology. The remaining third of the course is a study of natural resources -- land, forests, water, minerals, marine areas -- and their utilization.

In world geography, the emphasis is on continents, climates, lands, oceans, and seas of the world. There is considerable earth science in the natural science course in grade four and the second term of grade five. In grade four, the emphasis is on climatic factors, composition of the air, and meteorological observation. In grade five, the topics are the earth's crust, earthquakes, rocks, the solar system, solar and lunar eclipses, "the boundless universe," and artificial earth satellites.

Rocks and minerals receive little attention in these courses except as they might reflect the interest of a particular teacher.

The State Council encourages some study of minerals by offering rewards to anyone providing information on mineral deposits. The amount of the cash award is in proportion to the richness of the mine and may reach $3000.

Laboratory and field work are not a part of the geography courses. There is considerable work with maps and how to interpret them. Where equipment is available, teachers make extensive use of the overhead projector.

Examinations in the courses and for university admission stress mapping and scaling and the interpretation of maps. Students are expected to apply what they have learned to such problems as the proper location of hydroelectric installations, soil improvement, water control centers, distribution and suitability of agricultural lands and forests, location of ports, and suitable places for cities. The textbooks emphasize geography and geology of Third World countries; less emphasis is given to developed countries with the exception of the United States.

NATURAL SCIENCE (GENERAL KNOWLEDGE)

Grades four and five: Natural Science, 2 terms, 2 days per week. Total class periods, 136.

The natural science courses are offered in the last two years of primary school. In grades one, two, and three, students have outdoor contact with science phenomena in physical education courses. The reading textbooks for kindergarten and the early primary grades are rich in stories about science, inventions, animals, personal hygiene, and community sanitation.

The first term of grade four is mostly about weather, the composition of air, water and its changes in state, wind and heat expansion and contraction. Applied topics include the purification of water, flying in air, fire extinction, and environmental protection. The second term begins with a study of common animals with an emphasis on insects, birds, fish, and frogs. Plants are studied with a focus on seed plants and their parts such as the root, stems, leaves, flowers, and fruits. Applied topics deal with the control of harmful insects, silkworms, domestic animals, industrial crops, afforestation, and learning from animals.

In grade five, the course is about equally divided between human physiology and diseases, simple physics (levers, pulleys, sound, electricity, heat and light), and earth science and astronomy. Applied science topics are prevention of diseases, motion pictures, power and heat transmission, generation of electricity and its uses, artificial earth satellites, and wire and radio broadcasting.

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3. Two Worlds of Science Learning: A Look at the Germanies

In this age of ever-increasing technological complexity, I believe it is imperative that our scientific and technical leaders become aware of the challenges presented by the science education systems of our principal ideological and industrial international competitors. Here I am concerned with the industrial challenge of the Federal Republic of Germany and the ideological challenge of world communism, of which the German Democratic Republic is a representative model.

The two German states exist today at the cutting-edge of East-West confrontation in central Europe (Figure 3.1). With limited land area and energy sources, both countries have risen from the devastation of the post-World War II period to become two of the ten leading industrial nations in the world. The German Democratic Republic (GDR) now has the highest standard of living in Eastern Europe, and the Federal Republic of Germany (FRG) has attained one of the highest living standards ever. The GDR and FRG are, therefore, prominent representatives of the two major competitive world systems, and the educational systems in these two countries, although philosophically different in approach, have played a major role in their industrial and economic success.

In the following pages, I will consider an essential aspect of education in both countries, and one which leaders in each nation believe is fundamental to the economic health and well-being of any modern industrial nation -- namely, the area of science education.

Nearly forty years ago, both Germanies began the postwar development of their educational systems from the same baseline. In the aftermath of World War II, the West Germans (over the objections of the Allies) reinstituted the traditional approach to education that had been developed prior to the Nazi period. East Germany, on the other hand, with the same tradition, made fundamental changes in its system of compulsory education. Divergent social, economic, and political developments have resulted in very different approaches to compulsory education in the two countries today. However, both systems have high educational standards, rigorous training for teachers, respect for the teaching profession, and an assured means of providing science knowledge to their citizens. Given their common

Figure 3.1 The two Germanies

origin, the two Germanies offer a unique opportunity for comparing the effect of the two major ideological systems on science learning. Given the economic successes of both countries, and the emphasis each places on science education, they also offer useful points of comparison for those concerned about the state of science education in the United States.

SCIENCE EDUCATION IN THE GERMAN DEMOCRATIC REPUBLIC

The structure, content, and practice of compulsory education in the Communist countries of Eastern Europe is based on the Marxist-Leninist prototype developed in the Soviet Union. Although the systems for educating youth in all of these countries are similar, it is generally acknowledged that Communist compulsory education has achieved an exceptionally high level of development in the GDR, where the Marxist-Leninist approach to education was superimposed on a foundation of traditional German scholarship. This small country, only slightly larger than the state of Ohio and with a population of less than 17 million,[1] has applied the same sense of determination and rigor to developing its educational system as it has to winning gold medals at international Olympic competitions and to competing for market share in world industrial trade.

Education in the GDR

The German Democratic Republic is the most highly industrialized country in Eastern Europe, with more than half of its Gross National Product derived from the industrial sector. Per capita income in 1981 was $5340, the highest in Eastern Europe.[2] Moreover, its leaders believe that its present rate of economic development cannot be maintained or surpassed unless simultaneous efforts are made to intensify science instruction at the level of compulsory education. Communist educators consider their current "polytechnical" approach to general education to be the most effective method of teaching science yet developed. Within this framework, continual efforts are being made to elevate the level of science education in the GDR and to increase its effectiveness.

Although certain elements of the East German educational system may have real applicability for Western societies, they must be viewed in the broader context, with the understanding that East German society is dominated by a totalitarian framework in which other academic disciplines, such as philosophy, history, and economics, are rigidly controlled, with only the Marxist-Leninist interpretation tolerated. Additionally, the lives of East German citizens are thoroughly regimented, since all power emanates from the small cadre of individuals that make up the country's ruling elite. While a certain independence is occasionally tolerated in internal GDR affairs, foreign policy follows in totality that of the Soviet Union. In a very real way, East Germany defines itself by the leeway allowed by the Soviet Union and by how much distance it wants to keep

from West Germany at any given time.

Ideologically and economically, in East Germany, science education is a necessity. Ideologically, Communists feel a close kinship to the natural sciences, since the Marxist laws of dialectics not only provide a means of interpreting the social sciences, but also furnish science as a whole with its general principles of operation, with an approach to phenomena, and with a method of investigation. As a consequence of its all-encompassing nature, Marxism-Leninism provides contemporary Communist society with a closed, comprehensive world view of the physical as well as social environment.[3] A major factor underlying the emphasis on science education in the GDR and other Communist countries is, therefore, the view that science learning reinforces Communist theory.

For the East German economy, science education creates a broad knowledge base for the training of a skilled, technically oriented labor force. Because of the GDR's relatively poor natural resource endowment, its industrial growth depends on the development of "skilled-worker-intensive" and "science-intensive" industries. These in turn depend on the efforts of a wide range of highly trained technical workers and applied scientists rather than on the consumption of great quantities of raw materials.

Education in the GDR is guided and controlled by the Central Committee of the East German Communist party, the Socialist Unity Party of Germany. To understand education in a contemporary Communist society, it is essential to realize that what young people learn during the years of compulsory education is considered fundamentally important for the furtherance of communism. Curricula for compulsory education incorporate the basic values of Communist society and provide youth with the most comprehensive education possible to enable them as adults to contribute effectively to the development of industrialized Communist society.

The "ten-year general polytechnical secondary school" — the official name of schools attended by East German youth during their compulsory education -- stands at the center of the GDR's integrated educational system (Figure 3.2). Nearly all East German children between the ages of 6 and 16 attend one of the 5073 such general schools throughout the GDR.[4] Instruction proceeds according to curricula developed in the GDR Academy of Pedagogical Sciences. Educational uniformity is assured since these curricula are the legal basis of instruction and evaluation of learning outcomes.[5]

Teaching methods used in the general schools and the physical setting of the school environment are similar to U.S. schools. The basic organizational form is the class of about thirty children of nearly the same age in the lower grades and of somewhat fewer students in the upper grades. The instructional period is forty-five minutes, and instructional units vary in length and orientation depending on the topic and the instructional goals of the unit. But here the similarity to U.S. schools ends. Learning theory in socialist countries is based on the work of Vladimir Ilich

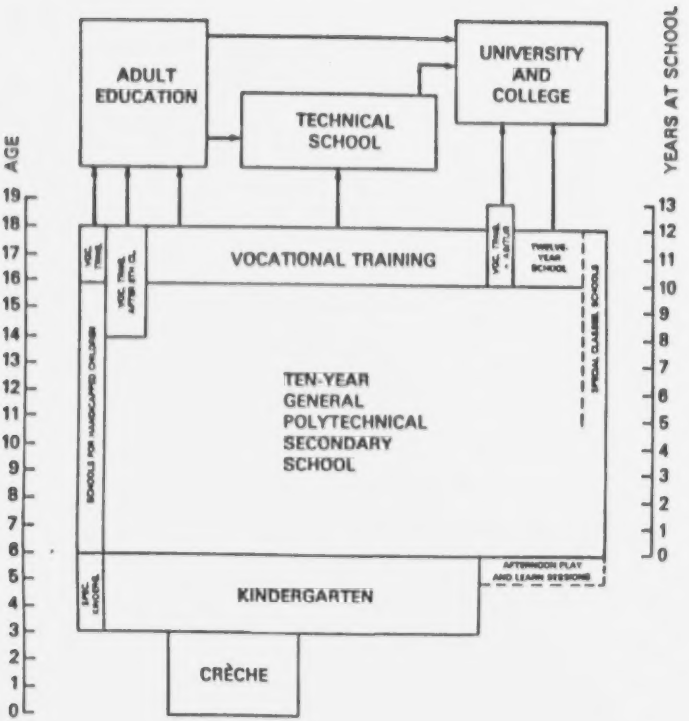

Figure 3.2 The educational system of the GDR

Lenin, the father of Communist education. More particularly, the learning process is based on his "copy theory of knowledge."

According to the copy theory, knowledge is a reflection, or copy, of reality. Events in the external world operate on the human senses giving rise to mental representations and concepts that depict, or mirror, the world outside. The human mind, in the process of physical and intellectual development, evolves an internal model of the natural and social environments comprising the external world. One's ability to interact with external environments depends on the degree of development of this internal model, and one's interaction with physical and social environments will be successful to the extent that the internal model correctly reflects external reality.

"Learning" is the dialectical process that occurs when the human perception of reality is tested through interaction with the external world. Depending on whether or not predictions are correctly formulated, results of an interaction either reinforce the original perception or lead to a new one. Teaching is perceived as the setting of objectives and the management of this process of approximation, and learning is a continual process of perfecting one's perception of reality through practical activity. The interaction between theory and practice for the purpose of honing perception is the essence of the polytechnical approach and underlies all aspects of instruction in contemporary Communist education.

Classroom instruction involves lectures, demonstrations, and discussions which are generally teacher-guided, question-and-answer sessions. Great emphasis is placed on learning fundamentals. For this purpose, traditional approaches to learning, such as memorization, are used, since Communist educators believe experience has proven those approaches to be the most effective for building a solid foundation of factual and theoretical knowledge. Student attainment of learning objectives is tested through a system of state-planned and state-regulated examinations given annually in all subjects at all grade levels.

The program for compulsory education is divided into three stages (primary, intermediate, and secondary; grades one through three, four through six, and seven through ten, respectively) and is comprised of six major instructional areas: social sciences, German language arts and literature, arts, and music; mathematics; natural sciences; polytechnical education and training; Russian language; and sports (Table 3.1).

At each stage in the education process, instruction conforms to the students' level of cognitive development. During grades one through three, the instructional emphasis is on language arts, literature, and mathematics; science learning is unspecialized and is integrated into this curriculum as Heimatkunde, essentially an introductory study of local vegetation and topography. Formal science instruction begins in the intermediate stage with the introduction of biology in the fifth grade and physics in the sixth; it attains maximum emphasis in the secondary stage, where nearly

one-fourth of the total curriculum is devoted to biology, physics, chemistry, and astronomy.

In considering the proportion of time allotted to the major instructional areas, it is important to note the effect of the interpenetration and overlap of disciplinary areas. For example, the area including the social sciences shows a proportionate decrease from the primary through the secondary stage; however, the practical application of the social sciences and their implications form a significant aspect of the polytechnical education and training course-complex and of the course entitled "Geography." Science subjects at the secondary stage amount to 22 percent of the curriculum; in addition, a major aspect of polytechnical education and training at this level involves the practical application of science theory in industrial and agricultural production processes. Thus, an average of 36 percent of the secondary school curriculum is actually devoted to science and technology. Together with mathematics, science and polytechnical education and training account for 51 percent of the secondary stage of compulsory education.

School and Industry - A Working Relationship

A unique feature of Communist compulsory education in the GDR is the "polytechnical approach to learning." Simply stated, this is an attempt to make education relevant by relating theoretical learning to practical activity. The polytechnical approach is both a pedagogical principle underlying the entire educational process and an area of academic instruction. As a pedagogical principle, polytechnical education expresses the basic Marxist concept of relating theory to practice: this is a total effort to relate events in the social and physical environments to their theoretical bases in Marxist-Leninist philosophy and in the natural sciences. As an area of academic instruction, polytechnical education and training is a course-complex whose purpose is to impart "the general scientific principles of all production processes and, simultaneously, initiate the child and the young person in the practical use and manipulation of the elementary instruments of all industries."[6]

Four specific objectives of contemporary polytechnical instruction in GDR schools are (1) to introduce students to the intellectual foundations of technology, (2) to qualify them for technical activity through development of technical capabilities and training in technical procedures, (3) to give them a broad prevocational background so that they can cope with changes in production processes, and (4) to train students in Communist social interaction.[7]

Polytechnical instruction in grades one through six consists of manual training and gardening instruction. Manual training takes place in specially equipped schoolrooms and includes work with paper, plastics, straw, leather, and wood. Gardening generally involves the care of a large kitchen garden which supplies

TABLE 3.1
Timetable for the 10-year general polytechnical secondary school (GDR)

Subject	Grade										
	Primary				Intermediate			Secondary			
	1 (1st half)	1 (2nd half)	2	3	4	5	6	7	8	9	10
German	11[a]	10	12	14	14	7	6	5	5	3	4
Drawing	1	1	1	1	2	1	1	1	1	1	-
Music	1	1	1	2	1	1	1	1	1	1	1
History	-	-	-	-	-	1	2	2	2	2	2
Civics	-	-	-	-	-	-	-	1	1	1	2
Geography	-	-	-	-	-	2	2	2	2	1	2
Mathematics	5	5	6	6	6	6	6	6	4	5	4
Physics	-	-	-	-	-	-	3	2	2	3	3
Astronomy	-	-	-	-	-	-	-	-	-	-	1
Chemistry	-	-	-	-	-	-	-	2	4	2	2
Biology	-	-	-	-	-	2	2	1	2	2	2
Industrial Arts	1	1	1	1	2	2	2	-	-	-	-
Gardening	-	1	1	1	1	-	-	-	-	-	-
Polytechnical Instruction	-	-	-	-	-	-	-	4	4	5	5
Introduction to Socialist Production	-	-	-	-	-	-	-	(1)	(1)	(2)	(2)
Technical Drawing	-	-	-	-	-	-	-	(1)	(1)	-	-
Productive Work	-	-	-	-	-	-	-	(2)	(2)	(3)	(3)
Russian	-	-	-	-	-	6	5	3	3	3	3

Sport	2	2	2	2	3	3	3	2	2	2	2
Second foreign language[b]	-	-	-	-	-	-	-	3	3	3	2
Needlework[b]	-	-	-	-	1	1	-	-	-	-	-
TOTAL[c]	21	21	24	27	30	32	33	35	36	34	35

Source: 35th Session of the International Conference on Public Education, 1975, Development of Public Education in the German Democratic Republic (Berlin: Ministry of Education, 1975), p. 37.

[a]Hours of classroom instruction per week.
[b]Optional course.
[c]Total number of class hours per week, including optional courses.

vegetables for the school cafeteria or the canteen of a school-associated factory.

In grades seven through ten, polytechnical education and training is tied into the very innovative "day of instruction in socialist production." Each school in the GDR is associated with a nearby industry, either a factory or an agricultural enterprise. All seventh through tenth graders spend one day each week in the factory studying polytechnical courses such as "Introduction to Socialist Production," "Technical Drawing," and "Productive Work." The curricula for these courses reinforce science, mathematics, and social science theory courses. The school-associated factories or agricultural enterprises provide classrooms for instruction as well as instructors, usually skilled workers who have taken education courses to qualify as technical instructors.

Two aspects characterize student training during the second stage of polytechnical instruction. One involves providing a comprehensive view of production processes, including construction and function of machines and their components, technological uses of machines and actual machines used in various branches of GDR industry, and some elements of electrical engineering. The second aspect centers on the course entitled "Productive Work." This practical course is based on the educational concept that the process of doing socially useful or productive work opens up a whole range of interests or incentives for teenagers. These include developing technical skills, developing curiosity about production processes, and, most importantly, learning how technical processes are related to scientific theory. Curricula for the course differ for schools located in rural-agricultural or predominantly urban-industrial areas and are adapted to the GDR's major industries. Students' technical and social experiences in industrial or agricultural work settings are reinforced through theoretical explanations in school.

The interrelationship between polytechnical training and science instruction has been stated as follows: "Science is . . . complete only when its results are transformed into practice. . . . For this reason, the evaluation and examination of science cannot be separated from technology."[8] Educators in the GDR, and in Communist countries in general, see that a knowledge of the laws and processes of science is fundamental to understanding modern technology, and they believe that science can be fully understood and appreciated only when it is related to technology. Therefore, they teach students to apply the laws of natural science to a variety of relevant technical situations in order to intensify the students' understanding of science and to develop their science-associated abilities, skills, interests, and attitudes.

"Science Education Is a Necessity!"

As noted earlier, the direct relationship between increased economic productivity and continued technological development is reflected in the emphasis and scope of natural science instruction

in the East German schools. In the view of GDR leaders and educators, only a broad education -- in both theory and practice -- in the natural sciences can equip a labor force with the technical knowledge and skills required to fulfill East German economic aspirations.

After completing the ten-year period of compulsory education, the top 10 to 12 percent of students prepare for the university. The remaining 88 to 90 percent of all general school students begin a two- or three-year period of vocational training. Many are trained for occupations requiring various degrees of technical and scientific knowledge, skills, and abilities. Separate areas of occupational training focus on the power and fuel industry; chemical, metallurgical, and building materials industries; mechanical engineering and vehicle construction; electrical engineering; electronics and precision engineering; the light, textile, and foodstuffs industries; building trades; agriculture and forestry; transport; post and telecommunications; and public health.

Since industrial society has a greater need for skilled workers and technicians than it does for academic professionals, only a small number of students are selected to prepare for the university. Of these, over half will eventually pursue professional careers in science and technology; these include research careers in mathematics, physics, chemistry, mechanical engineering and processing technology, electrical engineering and electronics, the building industry, medicine, and the agricultural sciences.[9]

The program for natural science instruction in the compulsory schools is structured so that the subject is integrated with other sciences, as well as with other areas of instruction. Since East German educators contend that all children who physically and mentally qualify for attendance in the ten-year general schools are capable of learning the required science material, all GDR youth must complete the program for science education. The required science instruction (Figure 3.3) is comprised of biology (six years, grades five through ten), physics (five years, grades six through ten), chemistry (four years, grades seven through ten), and astronomy (one year, grade ten). The curricula are spirally developed so that treatment of topic areas can be repeated with increasing complexity at successively higher grade levels (see Tables 3.2 - 3.5).

Major objectives of science education in the East German schools are:[10]

1. To provide insight into the system of natural science and to make apparent the relationships to other disciplines;

2. To make all students conversant with the basic laws of the natural sciences;

3. To examine the specific methods by which new knowledge in the natural sciences is acquired and to comprehend how this

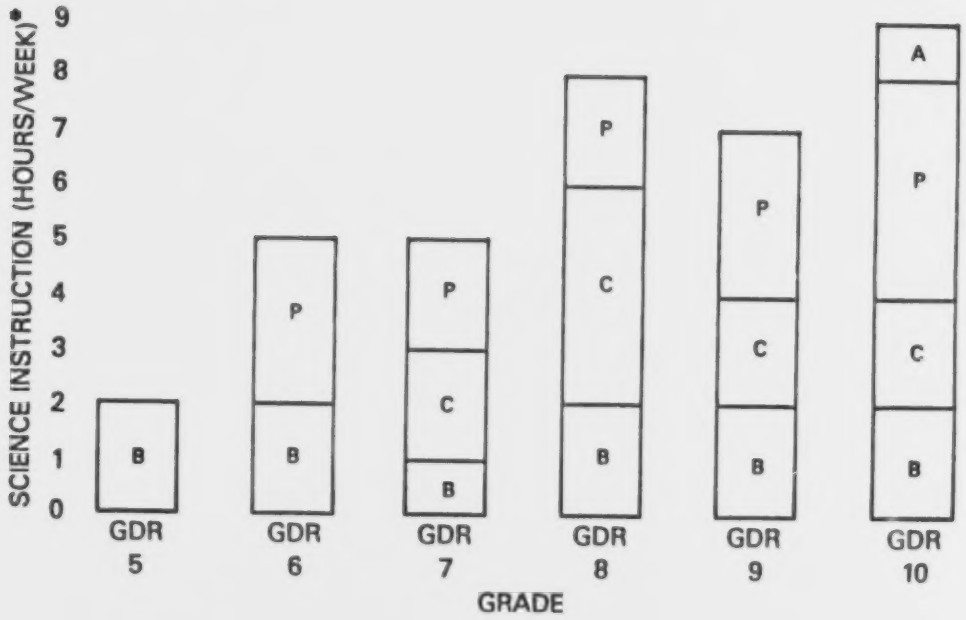

Figure 3.3 Distribution of required science instruction in the GDR

Note: *Hours = class "hours" (~45 minutes). A = Astronomy; B = Biology; C = Chemistry; P = Physics

TABLE 3.2
Biology curriculum, 10-year polytechnical secondary school (GDR)

Grade	Topics Included in the Curriculum
5	Introduction to the theory of life; structure and development, environmental relationships and capabilities of the vertebrate body (fish, amphibians, reptiles, birds, mammals); development and structure of seed plants.
6	The structure and importance of seed plant (families); structure, development, and environmental relationships of invertebrates (families) and the work of their organs.
7	Introduction to microscopy and cell theory (historical development of the microscope, structure and use of the microscope); single-celled life (animals, plants, bacteria); multicellular plants (algae, fungi, mosses, pteridophytes); cells, tissues, organs, organisms (universal functions of cells in single-celled organisms and occurrence of cell groups with specific functions in multicellular organisms).
8	Introduction to human anatomy, physiology, and hygiene; metabolism and energy transformation (nourishment and digestion, blood and lymph, respiration, energy transformation, elimination); the skin; locomotion and body posture (support organs and their functions, hygiene, injuries -- first aid); sense and nerve functions; hormones; reproduction and development (structure and function of the sex organs, embryos, post-natal development with emphasis on youth).
9	Anatomy and physiology of plants; organisms in their environment (living space, ecological potency, socialization, utilization and conservation of nature in the GDR).
10	Genetics (structure and function of hereditary factors, their distribution, mutation and modification); evolutionary theory (plants, animals, man); breeding plants and animals (goals, methods).

Source: Gerhart Neuner et al., Allgemeinbildung Lehrplanwerk Unterricht (Berlin: Volk und Wissen Volkseigener Verlag, 1973), pp. 206-208.

TABLE 3.3
Physics curriculum, 10-year polytechnical secondary school (GDR)

Grade	Topics Included in the Curriculum
6	Introduction to physics; bodies and matter (properties of physical bodies, volume, the motion of solid bodies, force and its effect on bodies, mass, the density of matter, the particle structure of matter, behavior of the volume of bodies when heated and cooled, temperature, change of state, thermal diffusion in matter, the structure of atoms and electric charge); optics (light sources and the propagation of light, reflection, refraction, and optical instruments).
7	Mechanics (force and its graphical illustration, mechanical work, simple machines, potential and kinetic energy, the Law of Conservation of Energy, power); mechanics of liquids and gases (pressure of liquids and gases in a closed container, gravitational pressure and its effects, pressure relationships in flowing liquids and gases).
8	Thermodynamics (heat energy including review and new material, Equation of State for an Ideal Gas, transformation of energy and the First Law of Thermodynamics); electrical theory (charge, intensity, and electric potential ; electrical energy, work, and power; electrical resistance, Ohm's Law; unbranched and branched electrical current circuits).
9	Mechanics (foundations of kinematics including the types of motion, acceleration of gravity, life and work of Galileo, projectile motion; foundation of dynamics including vector diagrams, Newton's Law, Newton's life and work, law of inertia; energy and the relation between potential and kinetic energy, energy transformation; circular motion; gravitation); electrical theory (electric field theory; magnetic field theory; electromagnetic induction; processes of electrical conduction -- a general model and applications).
10	Nuclear physics (atomic structure, elementary particles, atomic nuclei, the development and significance of atomic physics); oscillations (mechanical oscillations, electromagnetic oscillations -- alternating current -- and oscillating circuits); waves (mechanical waves, electromagnetic waves including light waves, Hertzian waves, and x-rays).

Source: Gerhart Neuner et al., Allgemeinbildung Lehrplanwerk Unterricht (Berlin: Volk und Wissen Volkseigener Verlag, 1973), pp. 187-89.

TABLE 3.4
Chemistry curriculum, 10-year polytechnical secondary school (GDR)

Grade	Topics Included in the Curriculum
7	Matter and change in matter (matter and its properties, physical process — chemical reaction, the science of chemistry — the chemical industry); oxygen and oxidation; introduction to chemical abbreviation (formula, valence, the Law of Conservation of Mass, the chemical equation); introduction to chemical calculation; hydrogen, reduction, "redox" reactions.
8	Atom and ion (atomic structure, the development of knowledge concerning the atom, ionic formation); chemical bonding (atomic bond, ionic bonding, transition from ionic to atomic bonding, the metallic bond, chemical reaction on the basis of atomic structure and chemical bonding); acids; bases; salts; periodic system of the elements; elements in Main Group VII; carbon as an element of Main Group IV; chemical calculation (mass relationships in chemical reactions, volume relations in chemical reactions); hydrocarbons (introduction to organic chemistry, alkanes, alkenes, alkynes, benzene, comparative treatment of hydrocarbons, technical extraction of hydrocarbons from petroleum and natural gas).
9	Chemical reaction (review and new material, chemical equilibrium, foundations of catalysis); some organic compounds with one functional group in the molecule; some organic compounds with several functional groups in a molecule; plastics, elastics, and chemical fibers.
10	"Redox" reaction and oxidation number; nitrogen as an element of Main Group V; sulfur as an element of Main Group VI; the science of chemistry as a productive force (the development of the science of chemistry and the chemical industry, physical-chemical foundations and economic problems in chemical-technological procedures, the contribution of chemical production to the development of the GDR national economy.

Source: Gerhart Neuner at al., Allgemeinbildung Lehrplanwerk Unterricht (Berlin: Volk und Wissen Volkseigener Verlag, 1973), pp. 197-99.

TABLE 3.5
Astronomy curriculum, 10-year polytechnical secondary school (GDR)

Grade	Topics Included in the Curriculum
10	Introduction to astronomy; the planetary system (the Earth as a celestial body; the Earth's moon; planetary motion and the struggle surrounding the heliocentric system; description and planetary physics; astronautics); astrophysics and stellar astronomy (the sun, the stars, the Milky Way system, and extragalactic systems); a systemized survey of astronomy from a historical perspective; an observational program.

Source: Gerhart Neuner et al., Allgemeinbildung Lehrplanwerk Unterricht (Berlin: Volk und Wissen Volkseigener Verlag, 1973), pp. 214-15.

knowledge can be applied to solve scientific-technological problems;

4. To make effective use of science education for developing a Marxist-Leninist world outlook; and,

5. To demonstrate the transposition of natural science knowledge to the realm of technology.

The neat integration of experiment and lecture which characterizes East German science instruction is an example of the Marxist-Leninist concept of uniting theory and practice in the educational process. This approach to science instruction is facilitated through the use of classroom-laboratories (Fachunterrichtsraueme) especially equipped for teaching biology, physics, or chemistry.

Underlying all GDR science teaching is the theory that interest in science comes from learning science, and that interest motivates more learning. In line with this theory, a series of extracurricular activities called Rahmenprogramme in the natural and social sciences was initiated in 1970 for ninth- and tenth-graders. After-school instruction is offered in microbiology, metallurgy, atomic structure, chemical technology, applied chemistry, electronics, and selected environmental problems. Response and interest in these activities has encouraged East German educators to make one such extracurricular activity mandatory for all ninth- and tenth-grade general school students.

Selection of Talented Youth

East Germany's limited size, population, and natural resources, together with its ambitious economic objectives, make the early discovery and encouragement of youthful talent a necessity, particularly in the natural sciences and science-related areas. One effective method for identifying science-talented youth has been the annual national competitions in the natural sciences and mathematics, called Olympiaden. In addition to identifying talented students, science competitions at the district level can be geared to a specific natural science for the purpose of evaluating the need for improving instruction in that science in that district. The science Olympiaden in physics, chemistry, and mathematics occur in successive rounds, from local to national levels. Winners of the national science competitions may go on to compete internationally with finalists from other, generally Communist, countries. A point system for the annual science competitions is used to make comparisons and diagnostic statements regarding scientific talent.[11] Highly talented youth have the option of continuing their compulsory education in specialized schools where, in addition to the mandatory curriculum, natural science study is accelerated and intensified. These competitions provide one more way of improving the present system of compulsory education in the GDR.

Teacher Training

Teachers in the GDR enjoy an esteem not generally shared by their American counterparts. Every year, on June 12th, "Teacher's Day" is celebrated to express public appreciation of and respect for the work teachers have done. Children present flowers, and greetings are sent by parents, industries that work together with the schools, and local officials. On "Teacher's Day," outstanding teachers are publicly honored and decorated at a government reception in East Berlin -- the title of "Honored Teachers of the People" is the highest distinction that can be conferred upon a teacher -- and successful teachers are given various titles, with salary increases, that indicate professional distinction. In addition, many teachers are elected as members of the East German legislature, the Volkskammer, as deputies of regional or local popular representative bodies, or as members of various commissions and trade union committees. Awards of this kind add to the status of teachers in East German society and serve as a further incentive.

Teacher salaries in the GDR are comparable to those of East German scientists and physicians (about 705 East Marks per month). But skilled workers can also earn this kind of salary, and this fact causes problems in attracting young people to the professions that involve university training. Monetarily, those who go into vocational training or begin to work directly after completing compulsory school have a two-year headstart over their peers who attend the universities. The East German government is currently trying to deal with this problem by providing all children at the age of fifteen years with stipends of 100 East Marks per month and by providing stipends of varying amounts for all university students.

Teachers for the ten-year general school are trained in universities, colleges, and pedagogical institutes in one of two programs. Primary stage teachers (grades one through four) are prepared at teacher training institutes through a four-year program that begins after they complete the tenth grade. Mathematics, German literature and language arts, and educational theory related to early childhood developmental processes are emphasized. Institute graduates qualify to teach three subjects in grades one through four: mathematics; German; and either music, physical education, art education, manual training, or gardening.[12]

Intermediate and secondary stage teachers (grades five through twelve) are trained at the university level, and since entry to the university involves a two-step screening process, they are among the brightest of their peers. The first screening occurs at the end of the tenth grade, when only those who rank in the upper 10 to 12 percent in grade point averages are permitted to pursue university-preparatory studies in the eleventh and twelfth grades. The national university entrance examination, usually taken at the end of the twelfth grade, provides a second screening since only those who pass it are eligible to attend universities in the GDR.

Future high school teachers are trained to teach in two related areas -- their academic major and minor subjects. The most common combinations for science teacher candidates are mathematics-physics and chemistry-biology or biology-chemistry. Science teachers can qualify to teach astronomy by completing a series of university-level astronomy courses. Nominally, these courses are open to all future teachers; however, the qualification to teach astronomy is usually sought by those who opt for the mathematics-physics combination.

All students, regardless of the training institution or the major/minor combination, are required to study the same core courses during the first two years. These include Marxist-Leninist theory, pedagogy, psychology, political-pedagogical activity, Russian, sports, speech training, techniques of working with audiovisual instructional equipment, and cultural-aesthetic education and training. In addition, students take courses in their major and minor fields and are introduced to teaching methodology (Table 3.6).

About 34 percent of the total teacher training program is devoted to courses in the major science area, and about 22 percent in the minor area. By the end of the second year of university training, future teachers are expected to have full mastery of both major and minor subject areas as they are taught at the intermediate and secondary stages of the general school.

The final two years are characterized by intensified work in the major field, the methodology of teaching in both major and minor fields, and extensive practice in the art of teaching. A thesis preparatory course provides future high school teachers with an opportunity to probe deeply into a specific area of their major field by surveying the content, methods, and trends in research and development in that area.

A major examination and a thesis which must be defended publicly are required of all intermediate and secondary stage teacher-candidates during the final year of professional training. Topics covered in the examination include the two teaching subject areas, teaching methodology in both subject areas, pedagogy, psychology, and Marxist-Leninist theory.

Principles for training teachers in East Germany are determined by the Minister of Education, who also approves the required curricula. Programs for preparing intermediate and secondary stage teachers in physics, chemistry, and biology were extensively revised and updated in the early 1980s. These changes are reflected in the curricula mentioned earlier and include an increase of thirty hours in the methodology of teaching in both major and minor fields and the addition of three courses -- speech training, audiovisual techniques, and cultural-aesthetic education and training -- during the first two years of teacher training. A new course has also been added for science majors. This course, offered in the seventh semester, is called "Ideological-Philosophical Problems of Natural

TABLE 3.6
Program of courses for training teachers for the intermediate and secondary stages

Course	Class Hours Required				Semester[a]							
	Total	Lecture	Seminar	Lab.	1	2	3	4	5	6	7	8
Marxism-Leninism	299	149	150	-	3	2	4	4	3	3	1	-
Pedagogy	134	75	59	-	2	2	2	2	-	1	-	-
Psychology	116	44	72	-	-	2	2	2	-	-	2	-
Political-Pedagogical Activity	64	-	32	32	2	2	-	-	-	-	-	-
Methodology of major and minor fields of specialization	250	-	-	-	-	-	-	2	6	4	4	-
Russian Language	76	-	76	-	2	2	1	-	-	-	-	-
Sports	212	-	-	-	2	2	2	2	2	2	2	-
Speech Training	12	-	12	-	-	-	1	-	-	-	-	-
Audiovisual Techniques	16	6	10	-	-	1	-	-	-	-	-	-
Cultural-Aesthetic Education and Training	32	-	32	-	1	1	-	-	-	-	-	-
Optional-obligatory courses	189	-	-	-	-	-	-	-	4	5	3	-
Major field of specialization	1090[b]	-	-	-	-	-	-	-	-	-	-	-
Minor field of specialization	690[b]	-	-	-	-	-	-	-	-	-	-	-

Source: Lehrprogramme fuer die Ausbildung von Diplomlehrern der allgemeinbildenden polytechnischen Oberschulen im Fach Physik (Berlin: Ministerium fuer Volksbildung, 1975), p. 82

[a]Numbers equal hours of instruction per week.
[b]Represents an average figure; slight variation in total hours required depending on fields of specialization.

Science," and has variants for each of the sciences. In the physics version, topics considered include the relation between Marxism-Leninism and science, the Marxist-Leninist concept of matter and its significance for physics, the materialist dialectic and physics, and philosophic problems of knowledge acquisition processes in physics.

The program for preparing mathematics and physics teachers was expanded in 1982 to upgrade the quality of physics teachers in the schools.[13] Under the new five-year program, students are being trained to be competent instructors in both areas (Table 3.7). Although physics and mathematics have traditionally been components of major and minor subject combinations in East German teacher training, students preferred to major in mathematics rather than physics to avoid laboratory work. Under the new program, experimental physics is central to the physics component of the curriculum, and laboratory training in physics has been increased by 75 percent to a total of seventeen semester hours. Physics lecture and seminar course requirements have been increased to fifty-two semester hours. Physics lecture and seminar course requirements have been increased to fifty-two semester hours, an increase of 24 percent over the previous requirements for physics majors. The mathematics component of the new program requires seventy-one hours in mathematics, or 33 percent of the total five-year curriculum. This includes forty-three semester hours in fundamental mathematics, plus courses in geometry, applied mathematics and information theory, probability and statistics, history of mathematics, and the methodology of mathematics instruction. The total number of semester hours required of East German teachers in mathematics and physics under the new program is 140, about 64 percent of the total five-year curriculum.

Teacher preparation in the GDR is effective: there is a direct correlation between the training program offered in the pedagogical institutes and universities and the curricula taught in the general schools. Methods for teaching the sciences are continuously reviewed by the Academy of Pedagogical Sciences and methodologists at pedagogical institutes. Teachers attend scientific meetings and read the literature to stay current. National congresses are held regularly, and conferences in specific subject areas take place every two years at both the national and international level among socialist countries. These provide teachers with an opportunity, at state expense, to attend lectures in their field of specialization and exchange ideas and experiences with their colleagues.

Reports submitted for presentation at teacher conferences and individual articles by teachers and methodologists are published in teaching journals devoted to specific subject specialties. For example, the journal Physik in der Schule (Physics in the School) is published monthly; through it, physics teachers make recommendations about methods they have used successfully and learn about new developments in the field. Similar journals exist for biology, chemistry, astronomy, and mathematics.

TABLE 3.7
Program of courses for training mathematics and physics teachers for the intermediate and secondary stages

Course	Total	Lecture	Seminar	Lab	Class Hrs. Required 1	2	3	4	5	6	7	8	9	10
Dialectical & Historical Materialism	75	32	43	--	3a	2	-	-	-	-	-	-	b	c
Political Economy	90	45	45	--	-	-	3	3	-	-	-	-	-	-
Scientific Communism	120	52	68	--	-	-	-	-	3	3	2	-	-	-
Electives in Marxist-Leninist Theory	30	15	15	--	-	-	-	-	-	-	-	2	-	-
Fundamental Mathematics	645	390	255	-	11	8	9	10	-	-	-	5	-	-
Geometry	60	30	30	--	-	-	-	-	-	-	4	-	-	-
Applied Mathematics & Information Theory	120	60	60	--	-	-	-	-	3	5	-	-	-	-
Probability and Statistics	75	45	30	--	-	-	-	-	5	-	-	-	-	-
History of Mathematics	30	30	--	--	-	-	-	-	-	-	2	-	-	-
Fundamental General Physics	615	210	210	195	7	9	9	7	7	2	-	-	-	-
Physics Laboratory	--	--	--	--	-	3	3	3	2	2	-	-	-	-
History of Physics	30	30	--	--	-	-	-	-	-	-	2	-	-	-
History of Education	30	15	15	--	2	-	-	-	-	-	-	-	-	-
Fundamentals of Pedagogy	30	15	15	--	-	2	-	-	-	-	-	-	-	-
Educational Theory	30	15	15	--	-	-	2	-	-	-	-	-	-	-
Didactics	30	15	15	--	-	-	-	2	-	-	-	-	-	-

General & Personality Psychology	30	15	15	--	-	2	-	-	-	-	-	-	-	-
Developmental Psychology	30	15	15	--	-	-	2	-	-	-	-	-	-	-
Educational Psychology	30	15	15	--	-	-	-	2	-	-	-	-	-	-
Diagnostics	30	6	24	--	-	-	-	-	1	1	-	-	-	-
Methodology of Mathematics Instruction	135	30	45	60	-	-	-	-	4	2	-	3	-	-
Methodology of Physics Instruction	135	30	45	60	-	-	-	-	-	4	4	1	-	-
School Experiments in Physics	60	--	--	60	-	-	-	-	-	2	2	-	-	-
Thesis	180	--	--	--	-	-	-	-	-	4	4	4	-	-
Health	15	15	--	--	-	-	-	-	1	-	-	-	-	-
Foreign Language	75	--	75	--	2	2	1	-	-	-	-	-	-	-
Sports	240	--	--	--	2	2	2	2	2	2	2	2	-	-
Audiovisual Techniques	15	--	15	--	-	1	-	-	-	-	-	-	-	-
Cultural & Aesthetic Education and Training	30	--	30	--	1	1	-	-	-	-	-	-	-	-
TOTAL	3255	1245	1475	375	29	29	28	30	30	29	25	17	-	-

Source: Discussion with Prof. Dr. Hansjoachim Lechner at the Humboldt University, East Berlin, November 1982.

[a]Numbers equal hours of instruction per week.
[b]Thesis work (6 weeks) and student teaching (13 weeks).
[c]Student teaching.

At the local, or Kreis, level, teachers who teach in the same subject area meet on a monthly basis in Fach Zirkeln (literally, specialist circles) to discuss issues of mutual professional interest. Since these meetings are intended to be a form of in-service training, faculty members from local universities are often invited to lead discussions on topical issues. Teachers must also update their professional knowledge every five years by earning university credits in two or three courses. These courses, offered during periods of school vacation, can be in the teacher's subject areas or in the methodology of teaching those subjects.

A more general means of raising the level of popular scientific understanding is through the Sontag Vorlesungen, or "Sunday Presentations." These Sunday morning science lectures are presented at universities and are open to the general public. The speakers are scientists who discuss new developments in their fields. The popularity of the Sunday morning lecture concept is growing, and educational planners in the GDR are beginning to think of ways to expand this approach to continuing education. Teachers benefit because it presents them with another option for staying current in their respective fields.

Some Current Issues

In the foregoing sections, positive features of science education in the GDR have been emphasized because it is to our advantage to be familiar with them. But it is also important for us to be aware of problem areas that exist.[14] One such area concerns teenage interest in science. Both sexes show a decreased interest in science in the upper secondary grades. Physics interest, for example, is high during the sixth grade and subsequently declines, with girls showing a greater declining interest than boys. Methodologists at the Humboldt University in East Berlin attribute this declining science interest among East German teenagers to present strategies for teaching science which, they say, do not conform to the way adolescents learn.

Declining teenage interest in science is causing concern in the GDR because too few young people are opting for careers in the sciences and mathematics. Only about one-third of all secondary students who are preparing for university entry indicate an interest for careers in science and mathematics, while the other two-thirds hope to pursue careers in the humanities and languages. The problem is that the East German economy has a greater need for scientists and engineers than it does for trained linguists and specialists in the humanities.

Related to the concern about the need for more university-level students in science and mathematics is a debate about the merits of the present program for learning science in the compulsory schools. The debate centers on whether teaching an array of sciences over a period of years is the preferable way of preparing students for science study in the universities. Proponents of this approach

argue that secondary school students must acquire a broad general foundation as preparation for specialization in the university. Critics, however, say that this approach leaves little opportunity for developing the kind of substantive knowledge of any one field that is required for making career decisions.

Although high school students generally acquire a good overview of the sciences, they have little basis for knowing what is involved in studying the various sciences and mathematics at the university level. This can lead to serious disappointment and failure when first-year university students are overwhelmed by program requirements in their selected course of study. For young people who fail and leave the university, reentry in the near future is problematical. In the GDR, decisions regarding career specialization are made before entering the university, and university places are awarded to fill quotas that conform to future socioeconomic requirements as part of the national economic planning process. The possibility of reentering the university is, therefore, greater for those who opt to specialize in areas where students are needed.

Another area of concern is the underrepresentation of women in certain fields. Although East German secondary schools provide equal opportunities for girls and boys to learn science and mathematics, the interest in science of girls at the secondary level tends to be lower than that of boys of the same age. At the professional level, the decreased interest in science among high school girls, together with a generally lower inclination than boys to pursue university studies, is parlayed into an under-representation of women in a number of fields. Even though it is acknowledged that this inequity is rooted in traditional patterns of female acculturation, there seems to be little awareness for the need to reverse the trend. At the Technical University in Dresden, for example, only 4 or 5 percent of all faculty members are women, and women hold only about 15 percent of the technical nonfaculty positions. Although the university claims to be interested in increasing the number of women on the science and technical faculties, university administrators say that not enough women apply. For those who do apply, however, there are no affirmative action programs to compensate for negative social pressures of the past and present, and men and women compete "equally" for the few faculty positions that are available.

Although women are underrepresented in fields such as mathematics and the physical sciences, they are overrepresented in medicine and in the teaching profession at the compulsory school level, since these are traditionally "women's fields." Currently, about 80 percent of all physicians and teachers are women, and efforts are underway to balance this inequality by bringing more men into both areas.

Despite statistics that show high levels of female employment in the GDR, I see an underlying naivety concerning the need for assisting women in attaining their social and professional potential across-the-board. However, despite the limitations imposed by the

system, there is, I believe, some interesting research being done in the area of science education at the compulsory school level. Since declining teenage science interest is a problem in many countries, including the United States and several European nations, it will be interesting to follow the East German research in this area.

Finally, it should be remembered that the present system of education was begun in 1965, so it is still too early to determine its full impact on the national economy and on the development of scientific creativity. However, the scope of mandatory science instruction, and the efforts to relate science to life through student involvement in industrial and agricultural production, are impressive indications of the belief at the highest government levels that all citizens must be prepared for effective participation in an era of high technology.

SCIENCE EDUCATION IN THE FEDERAL REPUBLIC OF GERMANY

During the postwar reconstruction in western Germany, the tripartite educational system that characterized compulsory education in pre-Hitler Germany was reinstituted. This system provided three separate tracks for educating West German children. One level led to vocational training, another provided basic preparation for mid-level technical and bureaucratic careers, and the third led to professional careers and positions of leadership in business, industry, and government. The Allies were critical of the tripartite approach because of the unequal educational opportunities in a system that tracked children largely on the basis of the financial and social circumstances of their parents. Allied efforts in the early postwar years to restructure West German compulsory education along more egalitarian lines were resisted by educators as well as by the political leadership, and the tripartite approach remains today as the basis of compulsory education in the FRG.

Despite criticisms of unevenness in its approach to compulsory education, the West German commitment to the further development of civilian research seems clear. While science spending by the United States and other western nations has shown a decline over the past two decades, it is on a long steep rise in the FRG. Between 1964 and 1979, West German spending on civilian research rose from $3.5 billion to $17.3 billion per year. In terms of its Gross National Product, this translates into an increase from 1.26 percent of GNP in 1964 to 2.26 percent in 1979. By comparison, the U.S. investment in civilian research peaked in 1966 at 1.96 percent of GNP, and has declined since then to 1.81 percent in 1981.[15] In the context of its science spending, West Germany has developed a highly creditable R&D infrastructure in the aerospace industries and related fields. To maintain its economic and scientific competitiveness, the West Germans will have to continue to make the kinds of financial and philosophical commitments to science education that they have in the past.

Education in the Federal Republic of Germany

In contrast to the uniform, centrally controlled East German educational system, West German secondary education is diverse and decentralized. There is a three-track educational program throughout the FRG, but the individual states (Laender) are responsible for their own programs. In each state, the Minister of Education is responsible for administering the school system. At the national level, there is a Permanent Conference of State Cultural and Educational Ministers which coordinates educational matters among the states and tries to minimize differences. In recent years, however, its efforts to minimize differences among the three tracks have met with only minor success. This is due largely to the opposing positions of two groups of states in West Germany -- those controlled by the Social Democratic Party, which favors comprehensive secondary schools, and those controlled by the Christian Democratic Union Party, which supports the status quo -- the strict, three-track system of separate schools.

Full-time school attendance is required for nine years, and part-time attendance is required for an additional three years. All West German children are provided with a uniform primary education which begins in the first grade at the age of six years. The period of primary education lasts four years (grades one through four) in all states except West Berlin; there it lasts six years.16 Children attend school about 210 days per year, alternating five- and six-day weeks, and are in classes between twenty and thirty hours each week, depending on the grade. The primary school curriculum typically includes German language arts and literature, mathematics, religion, music, art, and sports as well as introductions to social studies, history, geography, biology, chemistry, and physics.17

At age ten, most children and their parents face the difficult decision of choosing a secondary school -- a key decision in determining the child's adult social and economic standing in society. Possible choices include the secondary modern school (Hauptschule) with its prevocational orientation; the intermediate school (Realschule), which provides the secondary-level preparation for mid-level careers in industry, business, and government; the university preparatory academic secondary school (Gymnasium); and, in a few cases (about 2 percent of all secondary school students in 1978), the comprehensive school (Gesamtschule), which provides a unified approach to compulsory secondary education (Figure 3.4). Beginning in the mid-1970s, the transition to secondary education was eased somewhat through introduction of an "orientation phase" (grades five and six) in all three general education secondary schools. Although students enrolled in orientation courses can delay selecting a secondary school until the sixth grade, in the 1978-1979 school year, only about 15 percent of all students took advantage of this option.18

About 50 percent of all West German children enter the prevocational track (Hauptschule) after completing primary school. The educational program is typically five years (grades five through

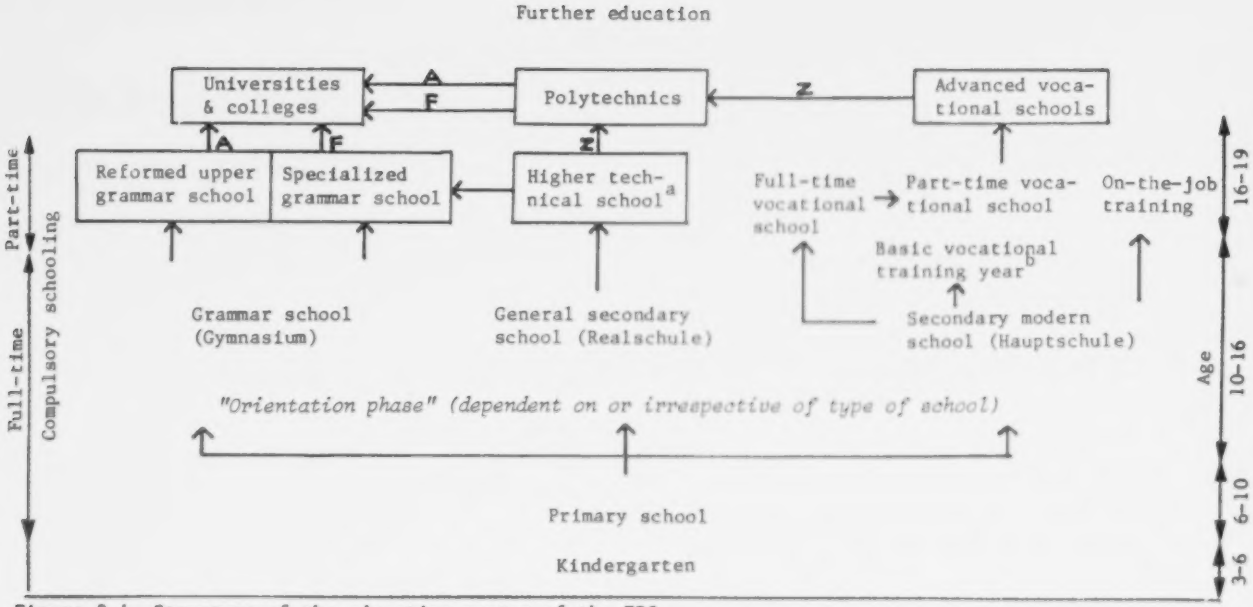

Figure 3.4 Structure of the education system of the FRG

Source: Information, 15, Public Document (Bonn: Press and Information Office, Government of the Federal Republic of Germany, 1980).

[a] Still experimental in some states. [b] For some pupils or apprentices: school experiments.

Note: A = general university entrance qualification; F = specialized university entrance qualification; Z = polytechnic entrance qualification.

nine) and students attend classes between thirty and thirty-three hours each week.19 The curriculum is oriented to practical subjects and preparation for employment and is the least demanding of the school types. About 30 percent of the course work is in biology, physics, chemistry, and other technical subjects (Table 3.8). At the end of the ninth grade, Hauptschule students can (1) complete the tenth grade and obtain the intermediate learning certificate which qualifies them to attend the higher technical schools, (2) take a job and receive on-the-job training while attending vocational school part-time under the "dual system," or (3) attend vocational school full-time to prepare for middle-level trade qualifications.

The Realschule, which prepares students for a variety of mid-level technical and bureaucratic careers in business, government, and industry, provides a somewhat less practical and more rigorous education than the Hauptschule. Students attend classes from thirty to thirty-four hours each week, and satisfactory completion of the tenth grade results in the intermediate learning certificate required for entry to the higher technical schools. Required courses include two foreign languages, mathematics, physics, chemistry, biology, and geography (Table 3.9). Graduates can opt (1) to go directly into employment and attend part-time vocational school for an additional two years, (2) enter a technical school that offers vocational training at the upper secondary level, or (3) attend the Gymnasium to work for the university entrance qualification (the Abitur).

The Gymnasium extends from grades five through thirteen and prepares students to take the Abitur examination, the successful completion of which is the precondition for admission to any German university. Traditional Gymnasien are oriented to modern languages, mathematics and the natural sciences, or the classics. Others emphasize the social sciences, economics, engineering and technical sciences, music, agriculture, home economics, or textile engineering.

Gymnasium curricula for grades five through ten typically include two foreign languages, mathematics, biology, physics, chemistry, and geography (Table 3.10). The number of class hours per week range from thirty to thirty-six, with variations among grades and states. Comparing Gymnasium courses with those of the Hauptschule and Realschule, certain features emerge as standard. In all three school types, mathematics instruction is required throughout the period of full-time schooling, and science courses, including biology, chemistry, and physics, are required and are taught over a period of years from grades five through ten.

At the upper level (grades eleven through thirteen), mathematics is required in all Gymnasien. To this the various types of academic secondary schools add two additional required subjects, one a foreign language and one a natural science in an area selected by the student. Subjects are taught in basic and intensified versions, and each student must select two intensified courses, of

TABLE 3.8
Timetable for the Hauptschule, state of Northrhine Westfalia (FRG)

Subject	Grade					
	5	6	7	8	9	10[a]
Religion	2[b]	2	2	2	2	2
German	5	5	4	4	4	5
Foreign language	5	5	4	4	4	4
Mathematics	4	4	4	4	4	4
Science	4	3	3	3	4	4
Social studies	3	4	3	3	4	3
Technical instruction	-	-	3	3	3	2
Music and art	3	3	3	3	2	2
Sport	3	3	3	3	3	3
Electives	1	1	2	2	2	3
TOTAL hours per week	30	30	31	31	32	32

Source: Synoptische Darstellung der Stundentafeln fuer den Sekundarbereigh I in den Laendern der Bundesrepublik (Landesinstitut fuer Curriculumentwicklung, Lehererfortbildung und Weiterbildung, 1978), unpublished document.

[a]An optional tenth year is offered in some states.
[b]Hours of formal classroom instruction per week.

TABLE 3.9
Timetable for the Realschule, state of Schleswig-Holstein (FRG)

Subject	Grade					
	5	6	7	8	9	10
Religion	2[a]	2	2	-	2	2
German	5	5	4	4	4	4
English	5	5	5	4	4	4
French or Danish	-	-	4	3	-	-
Mathematics	5	5	4	4	4	4
Biology	2	2	-	2	2	2
Physics	-	1[b]	2	2	2	2
Chemistry	-	-	-	2	1	2
Geography	2	2	2	2	-	2
History	-	1	2	2	2	-
Social studies	-	-	-	-	2	2
Technical instruction	1	1	1	1	-	-
Music	2	2	2	2	-	-
Art	1	1	1	1	-	-
Sport	3	3	3	3	3	3
Electives	2	2	-	-	6[c]	6[c]
TOTAL hours per week	30	32	32	32	32	33

Source: Synoptische Darstellung der Stundentafeln fuer den Sekundarbereigh I in den Laendern der Bundesrepublik (Landesinstitut fuer Curriculumentwicklung, Lehererfortbildung und Weiterbildung, 1978), unpublished document.

[a]Hours of formal classroom instruction per week.
[b]An integrated course in physics and chemistry.
[c]To be selected from the following subject areas: French or Danish; biology, physics, or chemistry; social sciences; and/or music, art, or technical instruction.

TABLE 3.10
Timetable for the Gymnasium, state of Hesse (FRG)

Subject	Grade					
	5	6	7	8	9	10
Religion	2[a]	2	2	2	2	2
German	4	4	4	4	4	4
First foreign language	5	5	4	3	3	3
Second foreign language	-	-	4	4	4	4
Mathematics	4	4	4	4	4	3
Biology	3	2	1	-	2	2
Physics	-	1	3	2	-	-
Chemistry	-	-	-	2	2	2
Geography	2	1	2	2	2	2
History	-	-	2	2	-	2
Social studies	1	2	-	-	2	-
Technical instruction	2	2	-	-	-	-
Music	2	2	1	1	1	1
Art	2	2	1	1	1	1
Sport	3	3	3	3	2	2
Electives	-	-	1	2	3	4
TOTAL hours per week	30	30	32	32	32	32

Source: Synoptische Darstellung der Stundentafeln fuer den Sekundarbereigh I in den Laendern der Bundesrepublik (Landesinstitut fuer Curriculumentwicklung, Lehererfortbildung und Weiterbildung, 1978), unpublished document.

[a]Hours of formal classroom instruction per week.

which one must be either a foreign language, or mathematics, or a natural science.20 Fewer subjects are studied from the twelfth grade on to permit greater concentration on individual subjects and a more in-depth approach.

Many students leave the Gymnasium after the tenth grade with the intermediate learning certificate. Currently, about 15 percent of each age group obtain the Abitur, and another 7 percent qualify for higher education with a specialized university entrance qualification. The latter are earned chiefly via the intermediate learning certificate and a subsequent two-year course at an upper secondary level technical school called a "polytechnic."21

The intrinsic inequity of the tripartite system remains an ongoing concern of critics of West German educational policy. Attempts to reform the system from within have brought higher education within reach of a broader spectrum of the population, but the Gymnasium continues to maintain its intellectual and "elitist" character. The majority of children, placed into the lowest educational track, the prevocational Hauptschule, continue to be handicapped by coming from less fortunate surroundings (urban versus rural), by their parents' lower educational level, or by poorer economic situations. Even so, an increase in the number of young people who obtained the Abitur during the past decade has resulted in more students seeking admission to universities than there are places available, a development having repercussions throughout the educational-vocational system. More and more Gymnasium graduates, excluded from the universities, are taking jobs and training positions traditionally available to mid-level secondary school graduates from the Realschule who, in turn, are taking job and apprenticeship opportunities away from a growing number of Hauptschule graduates. The lack of adequate university facilities and teaching staffs, coupled with a slow-down in economic growth, is causing displacement of increasing numbers of Hauptschule graduates. Many of these teenagers, representing the lower half of the spectrum of secondary school leavers, are being forced to join the ranks of the youth unemployed or to work part-time at odd jobs and as unskilled workers.22 The basic inequity, though, is that in most cases they were "programmed" for unequal job opportunities because of their academic record in the fourth grade at the age of ten years.

Teacher Training

Teachers for primary and secondary schools are trained in universities and at specialized institutions of university standing. To qualify for admission, these students must pass the standard national university entrance examination, which assures that only those of the highest academic ability can become teachers.

According to state regulations, students preparing for teaching careers must (1) take courses in education and in both a major and minor field of specialization, (2) fulfill practice teaching

requirements, and (3) pass two state examinations -- one after the course work is completed and another at the end of practice teaching. Course requirements vary depending on the state and the type of teaching, and practice teaching requirements range from eighteen months for Gymnasium and Realschule teacher-candidates to from one to three years for those preparing to teach in the primary school or Hauptschule. State teacher examinations generally consist of an oral examination in education, oral and written examinations in the major and minor fields of specialization, and a thesis which is presented at the first state examination.

Students can apply to take the first state examination after completing a relevant four-year course of university study.[23] If they pass, they can apply for the position of probationary teacher in any state and thus begin the second phase of teacher preparation. As probationary teachers, students become civil servants for the period of one and a half or two years, depending on the state. They receive about half the yearly salary of a regular teacher and teach between ten and fourteen hours per week, about half the regular teaching load. During this phase, students attend study seminars and lectures, generally in the region in which they hold the probationary position. At the end of probation, students may take the second state examination. If they pass, they can apply for a regular teaching position in any state. If they secure such a position, they become civil servants for life. Nearly all teachers in the Federal Republic are permanent civil servants.

More than half of the states in the FRG train teachers according to the type of school in which they will be teaching -- Hauptschule, Realschule, or Gymnasium. The remaining states prepare teachers for specific levels -- primary (grades one through four), secondary level I (grades five through ten), and secondary level II (grades eleven through thirteen). Teachers for the Gymnasium and secondary level II are usually trained in universities. Primary level (Grundschule) and Hauptschule teachers generally receive their training at colleges of education which, in some cases, are integrated into universities as schools of education. Teachers for the Realschule and secondary level I, whose course of study varies considerably across the states, can study either at universities or at colleges of education.

Compared to their counterparts preparing to teach in the Hauptschule, who are trained to teach in all areas, future Realschule and Gymnasium teachers must place greater emphasis on the major and minor fields of study.[24] The university curriculum for prospective Realschule or Gymnasium teachers typically consists of a major field of study, a minor field, and education courses. Generally, students are free to select their own major and minor combinations, but some states have made recommendations or issued regulations concerning discipline combinations with an eye to creating better employment possibilities.

Between 75 and 95 percent of the curriculum for future Gymnasium or secondary level II teachers is devoted to courses in

the major and minor fields, the balance being made up of methodology courses and practice teaching experience. Future Realschule teachers, or teachers for secondary level I, spend between 67 and 90 percent of the period of university study on courses in the major and minor subject fields, and between 10 and 33 percent of the time on education courses.

Two curricula from the University of Kiel serve to illustrate the similarities and differences in preparation of Realschule and Gymnasium teachers, since they are very similar to teacher training courses in universities throughout the Federal Republic (Table 3.11). Although the Kiel curricula are for the preparation and training of physics teachers, they are similar in format to many curricula currently being used for preparing biology and chemistry teachers for West German Realschulen and Gymnasien. Major similarities exist in the type of subjects required, the number of credits needed in the three major curriculum areas, and the time allotted.[25]

The basic curriculum during the first two years is largely oriented to courses in the major and minor subject areas, with somewhat fewer such courses being required of students preparing to teach in the Realschule or at secondary level I. A major difference occurs during the last two years of study: specialized training in the major field continues for students preparing to teach in the Gymnasium or at secondary level II, but future Realschule and secondary level I teachers focus more on discipline-oriented curriculum studies. The latter studies provide students with a basis and criteria for planning instructional materials such as syllabuses, textbooks, and teaching aids. Altogether, 106 semester hours are required in the major field for those preparing to teach in the Gymnasien and fifty-eight for students preparing to teach in the Realschulen.

A resolution of the Conference of Ministers of Education (21 May 1970) established "General Regulations on the Standards for the State Examination" for teaching careers in the Gymnasium. Teacher candidates are required to take the first state examination in their major field of specialization and, before applying to take the examination, must fulfill rigorous prerequisites. In physics, for example, prerequisites for admission to the examination include completion of the following minimum academic work:

- Lecture courses in experimental physics, about sixteen semester hours in foundations of classical physics, atomic physics, nuclear physics, solid state physics, and applications of physics;
- Lectures on theoretical physics, about twelve semester hours in mechanics, electrodynamics, quantum mechanics, thermodynamics, and relativity theory;
- Successful participation in at least three problem-solving courses, with at least one in theoretical physics;

TABLE 3.11
Model curriculum (physics) for preparing teachers for the Gymnasium and the Realschule

Semester	Teaching Post at the Gymnasium	Teaching Post at the Realschule
1	Compulsory: Introduction to Physics I (4h); Analysis I (4h) with problems (2h) Recommended: Problems connected with Introduction to Physics I (2h)	Compulsory: Introduction to Physics I (4h) Recommended: Problems connected with Introduction to Physics I (2h)
2	Compulsory: Introduction to Physics II (4h); Analysis II (4h) with problems (2) Recommended: Introduction to Applied Physics I (4h); Problems based on intro. to Physics II (2h)	Compulsory: Intro. to Physics II (4h) Recommended: Problems based on Intro. to Physics II (2h)[a]
3	Compulsory: Introduction to Physics III (3h); Theoretical Physics Ia (Mechanics I) (4h) problems (2h); Physical Practicum I or III (8h); Analysis III (4h) with problems (2h) Recommended: Introduction to Applied Physics II (2h)	Compulsory: Introduction to Physics III (3h); Theoretical Physics Ia (Mechanics I) (4h) with problems (2h); Physical Practicum I (8h) Recommended: none
4	Compulsory: Introduction to Physics IV (3h); Theoretical Physics IIa (Electrodynamics) for Prospective Teachers[b] (4h) with problems (2h) Intermediate examination	Compulsory: Introduction to Physics IV (3h); Physical Practicum II (8h) Lecture or seminar in discipline-related curriculum studies
5-8	Compulsory: Theoretical Physics II (Quantum Mechanics) (4h) with problems (2h); Theoretical Physics IV (Thermodynamics) (4h) with problems (2h); School-Oriented Experimental Practicum (8h); Theoretical Physics IIa (Electrodynamics) (4h) with problems (2h)[c]; Analysis IV (4h) with problems (2h)	Compulsory: School-Oriented Experimental Practicum (8h)

Compulsory from which courses can be selected: seminar on specialized physics (2h); seminar on discipline-related study (2h); two advanced practica from General Physics (Ia-8h), Electronics (Ib-4h), Nuclear Physics (Ic-4h), or Special Areas (II-4h)	Compulsory from which courses can be selected: seminar on specialized physics (2h); seminar on discipline-related study[d]
Recommended: introductory and special lectures and seminars from the main points of physics research and from discipline-related curriculum studies, particularly with regard to the subject the student intends writing his state examination on	Recommended: Introductory and special lectures and seminars from the main points of physics research and from discipline-related curriculum studies, particularly with regard to the subject the student intends writing his state examination on

Source: Wolfgang Buender and Karl Frey, Discipline-related Curriculum Studies as Part of the Study Course for Science Teachers of Grade 5-13 at the Universities in the Federal Republic of Germany. Institute fuer die Paedogik der Naturwissenschaftern (IPN) Report in Brief #21. Kiel, 1980. pp. 32-33.

Note: Total semester hours in major field is 106 (98 compulsory, 8 recommended) for the Gymnasium teaching post and 58 (54 compulsory, 4 recommended) for the Realschule teaching post.

[a]A record of efficiency in one field of problems is required.
[b]Instead of Theoretical Physics II, the course of Theoretical Physics Ib (Mechanics II) (4h) with problems can be taken. This course is also part of the course of study for a diploma.
[c]If not taken up in the basic course of study (see note b).
[d]Altogether, 6 semester hours of discipline-related curriculum study must be taken in the basic and main courses of study.

- One physics seminar;
- Physical laboratory, about ten hours per week;
- An advanced laboratory, eight hours per week, to learn independent construction of experiments and demonstrations;
- Additional lectures and a laboratory or seminar in the area of physics selected for the thesis topic.

The other sciences and mathematics have equally rigorous coursework prerequisites for admission to the first state examination. For Gymnasium teacher-candidates, this examination involves written and/or oral examinations, depending on the major field of specialization, in addition to the requirement that students publicly defend their major scientific paper, or thesis.

As mentioned earlier, nearly all teachers in the Federal Republic are permanent civil servants. The advantage for West German teachers is that, in addition to the fringe benefits to which they are entitled, their pay is competitive with other jobs in the civilian sector. In 1983, the annual salary of Gymnasium teachers began at about 43,000 Deutsch Marks (DM), increasing to about 65,000 DM for teachers without administrative responsibilities and to about 80,000 DM for those with such responsibilities.[26] Cost-of-living adjustments are made on a yearly basis. The salaries of teachers in the other two school types were somewhat lower, with the average yearly income of a Realschule teacher at about 43,000 DM. By comparison, the annual income of technical white collar workers (graduates of technical institutes rather than universities) ranged from about 23,000 DM to 45,000 DM, with the possibility of earning an additional 10 percent for outstanding job performance.[27]

Although teachers are paid comparatively well in the Federal Republic, inducements to work in the private sector are increasing just as they are in other industrialized countries. New technologies are creating a broader and more varied employment market for those who have the requisite knowledge and skills. And as employers make jobs more attractive through inducements of higher pay and other benefits, people with degrees relating to the needed skills will be drawn off from the teaching profession, leaving teacher shortages in the sciences and mathematics. In fact, there is already a mild shortage of science teachers in the Gymnasien and Realschulen, since for the past several years, scientists have preferred to take positions in industry rather than go into the teaching profession.

Learning Science in West German Schools

Noteworthy trends in West German primary school science (grades one through four) are the emphasis on discipline-oriented instruction and an increase in time devoted to science learning in

the total curriculum. Primary school science study is an aspect of the instructional area known as Sachunterricht, which may be translated as "instruction in practical knowledge." During the past decade, Sachunterricht has evolved from the traditional Heimatkunde, oriented to learning about the geography and nature of the immediate environment, to more general, discipline-based instruction that has the goal of conveying perspectives in sociology and politics, economics, the natural sciences, and technology.[28] Sachunterricht accounts for nearly half of the total instruction time at the primary level -- about fourteen out of thirty hours each week -- and about 50 percent of this time -- seven hours per week -- is devoted to science.

At the secondary level (grades five through ten), science education is comprised of biology, physics, and chemistry.[29] In most states, biology is taught as a separate subject in the fifth and sixth grades, while chemistry and physics tend to be taught in combination. In these grades, about two hours each week are spent on biology and one hour on physics-chemistry combination, for an average total time of three hours each week on science instruction.

The tendency to teach the sciences in combination in grades seven through ten is most pronounced in the Hauptschule, where science is often taught as a combination of physics-chemistry, chemistry-biology, or physics-chemistry-biology. In most Realschulen and Gymnasien, these sciences are taught as separate subjects in these grades. The total time spent on science instruction in grades seven through ten is about 3.0 hours per week in the Hauptschule, 3.5 in the Realschule, and 3.0 hours per week (seventh grade) to 5.5 (tenth grade) in the Gymnasium. Although biology, physics, and chemistry are taught in each type of school in grades seven through ten, there is some difference in emphasis at each grade level (Figure 3.5).

The potential for diversity in West German secondary education is reflected in the variety of science programs offered across the country. In the state of Saarland, for example, nearly 25 percent of the total curriculum is devoted to science instruction in ninth and tenth grade Gymnasium classes, whereas it accounts for less than 6 percent of the total curriculum in seventh grade Gymnasium classes in the state of Lower Saxony. In general, the total average time spent on science instruction in grades five through nine or ten in all three school types ranges from 14.9 percent of the total curriculum in the state of Rhineland-Palatinate to 11 percent in the state of Lower Saxony.

Looking at the country as a whole, no particular science is emphasized over another -- rather the emphasis varies from state to state and according to school type. Differences do exist, however, in the approach to science learning. The orientation of the Hauptschule is typically practical, that of the Realschule tends to be technical, and the Gymnasium has a more theoretical and research-based orientation.

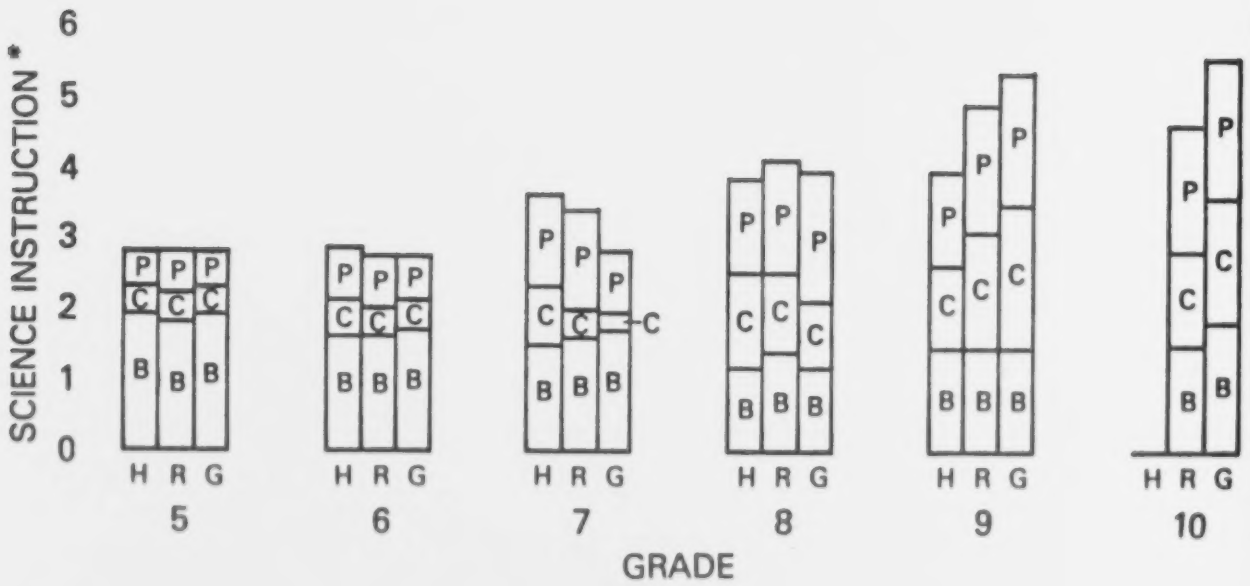

Figure 3.5 Distribution of required science instruction in the FRG

Source: Data from the Institute for Science Education, Christian Albrechts University, Kiel.

Note: * = class "hours" (~45 minutes).
H = Hauptschule; R = Realschule; G = Gymnasium; B = Biology; C = Chemistry; P = Physics.

The biology curriculum is more uniform across school types than either the physics or chemistry curriculum, but in nearly all states, Hauptschule students receive less biology instruction (Table 3.12). Although traditional biology topics continue to be taught on a one-time basis in many states, there is a growing tendency to implement spiral curriculum patterns so that topics can be treated with increasing complexity at successively higher grade levels.30 The basis of biology instruction at all grade levels and in all schools is observation of life processes, and student experiments are emphasized.

The three major areas of biology instruction are zoology, botany, and human biology. Zoology is usually emphasized in the fifth and sixth grades. Human biology is stressed in grades seven through ten in the Hauptschule and Realschule, while zoology is emphasized slightly more in the Gymnasium. Across states and school types, botany gets the least emphasis.

Physics instruction in West German secondary education has become more mathematical during the past ten years, and topic areas are being treated with greater intensity (Table 3.13). 31 The emphasis is on learning physics vocabulary, planning and carrying out experiments, building hypotheses, and learning to pose technical problems. A general tendency toward strengthening the relevance of physics instruction is reflected in the increased teaching of technical applications of physics in industry. This tendency is most pronounced in the Hauptschule, where physics instruction is generally oriented to the practical and to student interest rather than to developing a theoretical understanding of the subject. In the Realschule, on the other hand, curricula have been developed that are nearly as rigorous as those of the Gymnasium, although they retain a relatively strong technical orientation and a less theoretical approach to instruction than the Gymnasium curricula.

Chemistry is emphasized less in West German secondary schools than either biology or physics (Table 3.14). In all three school types, chemistry accounts for about 3 percent of the total instruction time in grades five through ten. In comparison, biology accounts for about 5 percent of the curriculum in each type of school, and physics for about 4 percent of the curriculum in the Realschule and Gymnasium in grades seven through ten. As with physics, Hauptschule chemistry is generally based on topics of potential use and interest to students bound for vocational schools. Again, chemistry tends to be technically oriented in the Realschule and more theoretical and less technical in the Gymnasium. 32

Teenage Interest in Science

West German teenagers become less interested in science as they get older, according to recent studies.33 While there is a decline in interest for science courses in general, this is particularly true for physics-oriented courses. The number of students in

TABLE 3.12
An overview of the biology curriculum (FRG)

Grade	Hauptschule	Realschule	Gymnasium
5	Plant morphology & anatomy Plant physiology Plant classification Animals with backbones Animal classification Human biology Sex education Health education Cells & the microscope	Plant morphology & anatomy Plant physiology Plant classification Animals with backbones Animal classification Human biology Sex education Health education Cells & the microscope Ecology	Plant morphology & anatomy Plant physiology Plant classification Animals with backbones Animal classification Human biology Sex education Health education Ecology
6	Plant morphology & anatomy Plant physiology Plant classification Animals with backbones Animal classification Human biology Sex education Health education Genetics, cells, & individual development	Plant morphology & anatomy Plant physiology Plant classification Animals with backbones Animal classification Human biology Sex education Health education Ecology Topics in applied biology	Plant morphology & anatomy Plant physiology Plant classification Animals with backbones Animal classification Human biology Sex education Genetics, cells, & individual development Ecology Topics in applied biology
7	Human biology Health education	Ecology	Animals with backbones Animals without backbones

	Animals without backbones Genetics, cells, & individual development Ecology		Ecology
8	Human biology Health education Animals without backbones Genetics, cells, & individual development Ecology Ethnology	Health education Animals without backbones Ecology	Plant classification Animals without backbones Ecology
9	Human biology Sex education Health education Genetics, cells, and individual development Evolution Topics in applied biology	Human biology Sex education Genetics, cells, and individual development Evolution Ethnology	Human biology Sex education Genetics, cells, & individual development Evolution Plant classification Topics in applied biology
10	Human biology Sex education Health education Genetics, cells, and individual development Evolution Topics in applied biology	Human biology Sex education Genetics, cells, and individual development Evolution Ethnology Topics in applied biology	Human biology Sex education Health education Genetics, cells, & individual development Evolution Topics in applied biology

Source: Data from an array of unpublished materials provided to the author by the Institut fuer die Paedagogik der Naturwissenschaften, Christian Albrechts University, Kiel, Federal Republic of Germany, 1982.

TABLE 3.13
An overview of the physics curriculum (FRG)

Grade	Hauptschule	Realschule	Gymnasium
5	Simple electric circuits Temperature, heat expansion	Simple electric circuits	Simple electric circuits
6	Light propagation Shadows, reflection Magnetism	Magnetism	
7	Optical lenses, light rays, simple optical instruments Force, weight, pressure, buoyancy, simple machines Electric current, parallel & series circuits, potential, resistance Spectra Heat propagation, heat theory	Light wave propagation, shadows, reflection, light rays, lenses, simple optical instruments Spectra Electric current Magnetic field, electric conductors Force, weight, pressure, buoyancy	Light wave propagation, shadows, reflection, lenses
8	Acoustics Work Electrostatics, electric power & work Induction, generators Electromotor, transformers, the magnetic field	Electrostatics, electric potential Efficiency, simple mechanical machines Heat theory	Force, weight, work, simple mechanical machines, simple motion Temperature & heat propagation, heat transfer Acoustics Simple optical instruments

			Electrostatics, electric current, potential, resistance Simple optical instruments
9	Nuclear energy, nuclear reactors, radioactive radiation Heat energy, steam engines Simple motion Rockets Semiconductors Atomic structure, elementary particles	Electric resistance, parallel & series circuits Electric efficiency & work	Parallel & series circuits Induction, generators, transformers Electric energy, potential, work Force, buoyancy Gas laws Heat energy & steam engines
10		Semiconductors, electronics, transformers, induction, generators Energy transformation Simple motion Atomic structure, elementary particles Nuclear energy, nuclear reactors, radioactive radiation	Nuclear energy, nuclear reactors, radioactive radiation Semiconductors Transformation of energy The magnetic field & electrical conductors Atomic structure, elementary particles

Source: Data from an array of unpublished materials provided to the author by the Institut fuer die Paedagogik der Naturwissenschaften, Christian Albrechts University, Kiel, Federal Republic of Germany, 1982.

Note: Magnetism and heat theory are covered in different years, depending on the state.

TABLE 3.14
An overview of the chemistry curriculum (FRG)

Grade	Hauptschule	Realschule	Gymnasium
7	Homogeneous & nonhomogeneous matter Symbols for elements & compounds Simple separation processes Nonmetals (oxygen, hydrogen, carbon) Metals		
8	Heavy metals, nonmetals (sulfur, nitrogen), acids & their salts, hydroxide Atomic, molecular and aggregate structure Reaction processes Electrochemical reactions Production processes	Homogeneous & nonhomogeneous matter Symbols for elements, compounds, & reactions Topics in inorganic chemistry: light metals, nonmetals, acids & their salts, hydroxides	Homogeneous and nonhomogeneous matter Simple separation processes
9	Organic matter Atomic, molecular, & aggregate structure Building materials & raw materials Nutrition, food production & food processing	Periodic system Electrochemical processes Structure symbols Topics in inorganic chemistry: light & heavy metals, nonmetals, salts Production processes	Atomic, molecular, & aggregate structure Energy in reaction processes Stoichiometric laws & calculations Symbols of elements, compounds & reactions

	Nutrition, food production & food processing	Topics in inorganic chemistry: light & heavy metals, nonmetals, acids & their salts, hydroxides Environmental chemistry
10	Organic matter Washing & disinfecting	Atomic, molecular, & aggregate structure Periodic system Topics in inorganic chemistry: nonmetals, acids & their salts, and salts

Source: Data from an array of unpublished materials provided to the author by the Institut fuer die Paedagogik der Naturwissenschaften, Christian Albrechts University, Kiel, Federal Republic of Germany, 1982.

Note: Other topics are covered in some states in different grades: the periodic system, energy in reaction processes, stoichiometric laws and calculations, symbols for structures and reactions, salts, environmental chemistry, washing and disinfecting, energy conservation, fire prevention and fighting, philosophical aspects of chemistry.

Other topics covered in some states at different grade levels: simple separation processes; atomic, molecular and aggregate structure; laws governing reaction processes; stoichiometric laws and calculations; gas laws; further study of nonmetals; construction materials and raw materials; environmental chemistry; energy conservation; fire prevention and fire fighting; philosophical aspects of chemistry.

Other topics covered in some states in different grades: laws governing chemical reactions; electrochemical processes; gas laws; the law of mass action; structure symbols; analytical procedures; construction materials and raw materials; production processes; environmental chemistry; nutrition, food production and food processing; washing and disinfecting; energy conservation; fire prevention and fire fighting; philosophical aspects of chemistry.

Gymnasium grades eleven through thirteen who take either basic or intensive physics courses is described as alarmingly low. During the 1979-1980 school year, for example, only 33 percent of the students in grades eleven through thirteen opted to take physics courses, compared to 40 percent in chemistry courses and 81 percent in biology courses. Of those enrolled in intensive physics courses, only 10 percent were girls.

Reasons given by students for deciding not to enroll in physics courses in the upper secondary grades are that they consider the subject to be too difficult and wide-ranging and that they are afraid of getting poor grades which could make them ineligible for admission to the universities. Students also indicated that they were put off by physics courses in the lower grades (five through ten), saying that:

- They were not sufficiently motivated by their teachers in the lower grades, and perceived physics to be boring, dry, and no fun;
- Their interests were not generally taken into account;
- Too little attention was given to technological applications;
- The role and importance of physics for society was not adequately demonstrated;
- If more experiments had been done in grades five through ten, they would have been more interested in taking physics courses in the upper grades (eleven through thirteen).

Other West German studies have addressed questions such as, What kind of interest do fifth through tenth graders have in physics and technology, and how does this interest change with grade? Is the interest of girls in science similar to or different from that of boys? The results indicate a significant decrease of interest in all areas of physics for girls between grades six and seven, and for boys between grades seven and eight. Both boys and girls show a steady decrease in interest in zoology between grades five and nine. There is a general decline of interest in botany in both sexes from the fifth through the ninth grades, although girls show a brief increase between grades seven and eight, and boys' interest evens off between the eighth and ninth grades. Girls' interest in environmental issues increases from grades seven through nine; for boys, it increases between grades eight and nine. Girls become more interested in anthropology between grades seven and nine, and boys show a much lower but slight increase in interest between grades eight and nine.

Other findings indicate that both girls and boys are more interested in technical subject matter than they are in physics, a

preference that is more pronounced in boys. Out-of-school activities that are related to physics and technology have a positive effect on students' grades in physics, and this effect is stronger for girls than for boys. Both girls and boys were interested in technical equipment, but girls were more interested in natural phenomena in general, while boys had a greater interest in electrical phenomena and equipment and in contemporary problems in physics and technology.

At the primary level (grades one through four), both girls and boys were found to be equally interested in science, and that interest was high. Possibly this is due to the fact that science instruction at this level tends to be oriented toward the experiences and environment of children. Thus, the decline in science interest starting in about the fifth grade may be related to a deemphasis in this approach to instruction. The West German research in this area suggests that teenage interest in science can be promoted by making instruction more relevant through greater emphasis on problems related to daily life and technical application and by demonstrating interrelations between technical-scientific and social-economic developments.

COMPARING SECONDARY SCHOOL SCIENCE AND MATHEMATICS IN EAST AND WEST GERMANY

Science education in East Germany is based on the Marxist-Leninist conviction that science and life are closely related. The emphasis on science in compulsory education reflects both the role of science in Communist philosophy and the importance attributed to science and technology in contemporary Communist society. Major objectives of the GDR polytechnical approach are to emphasize the nobility of labor and to show the role of science in industrial society. Virtually all East German youth are provided a uniform education in science and mathematics within the framework of the ten-year general polytechnical secondary school, and obtain a wide-ranging familiarity with scientific theories and their applications in modern technology.

By contrast, science literacy in West Germany is dependent on the type of secondary school attended. Fifty percent of West German youth attend the Hauptschule and learn practical science structured around topics relevant to life at home and in the workplace. The 20 percent of teenagers who attend the Realschule learn technically oriented science of potential use to future mid-level bureaucrats and managers in business, government, and industry. The 30 percent of all secondary students who attend the Gymnasium obtain a theoretical and research-oriented understanding of biology, physics, and chemistry that prepares them for the university.

Time spent on secondary school science in West Germany varies depending on the state in which the school is located, school type, and grade level. The total time devoted to science instruction increases steadily from grades six through ten in all schools. The average time for required science instruction is 3.4 hours per week

over a five-year period in the Hauptschule, 3.7 hours per week over a six-year period in the Realschule, and 3.9 hours per week over six years in the Gymnasium. By comparison, nearly 100 percent of all young East Germans participate in a science program that has both a theoretical and a technical orientation. The average time required for science instruction in the GDR is 5.8 hours each week over six years (grades five through ten), and includes instruction in biology, physics, chemistry, and astronomy, plus a year of physical geology in the ninth grade as part of the geography curriculum.

Looking at science subject emphasis across grades in the FRG, biology is emphasized most in all three school types in grades five through seven, with considerably less time devoted to physics in the fifth and sixth grades and still less time spent on chemistry. Beginning in the seventh grade, physics and chemistry are stressed more, with increasing emphasis in each subsequent year. In the upper grades, all three sciences receive about equal emphasis (Figure 3.6). In East Germany, biology is introduced in the fifth grade. However, East German educators consider physics education of fundamental importance to the entire program of science education and polytechnical instruction, and physics is emphasized in the sixth, ninth, and tenth grades. In the eighth grade, chemistry is emphasized to convey an in-depth understanding of the structure of matter and energy.

By contrast, in the United States, a typical pattern of science instruction involves general science instruction for about three hours each week in grades five and six, one year of physical or biological science in either the seventh or eighth grade, for an average of about 2.5 hours of science instruction per week over the two-year period (grades seven and eight). In about half of the states, one more year of science in grades nine through twelve (an average of 1.7 hours per week) is required for graduation from high school.

In the GDR science instruction accounts for nearly one-fourth of the total curriculum for grades five through ten, as much as in the West German secondary schools. The Gymnasium and Realschule devote about 12 percent of the total curriculum to science, and the Hauptschule, about 11 percent. By comparison, in grades five through ten in the United States, science accounts for about 8 percent of the total curriculum in over half of the states, less in about 12 percent of the states, and more in 21 percent of the states (Figure 3.7).

Mathematics makes up 13 percent of the curriculum in all schools in West Germany, and 16 percent in the GDR. In the United States, it comprises 12 percent of the curriculum in grades five through twelve in more than 50 percent of the states, less in 22 percent, and more in 21 percent of the states.[34]

In the Federal Republic, four hours of instruction in mathematics is required each week over a five-year period in the Hauptschule and over a six-year period in the Realschule and

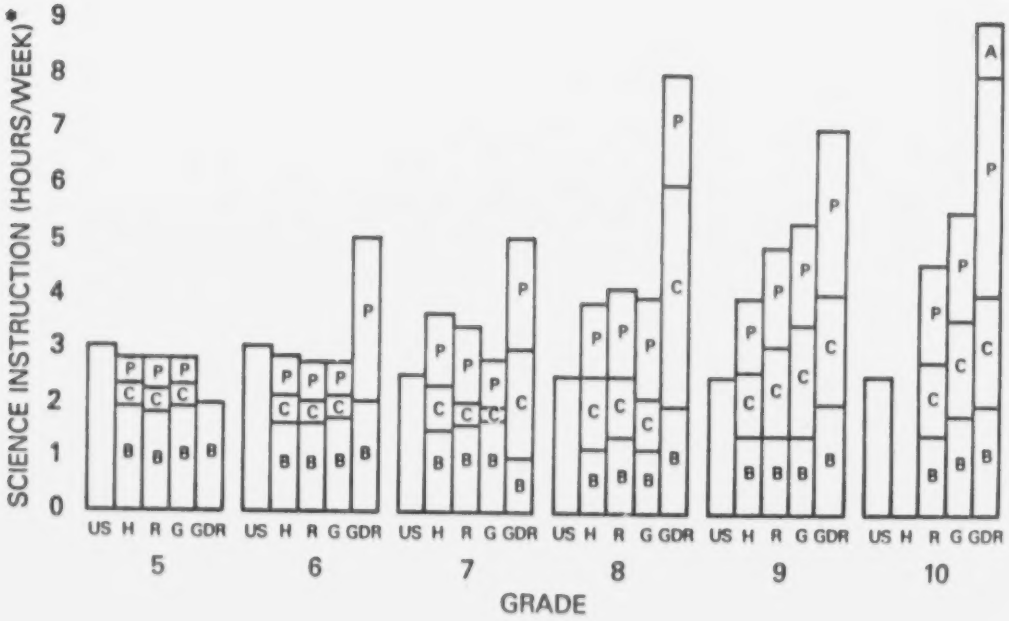

Figure 3.6 Distribution of required science instruction in the U.S., FRG, and GDR

Note: *Hours = class "hours" (~45 minutes).
US = United States; GDR = German Democratic Republic; H = Hauptschule; R= Realschule; G = Gymnasium. A = Astronomy; B = Biology; C = Chemistry; P = Physics

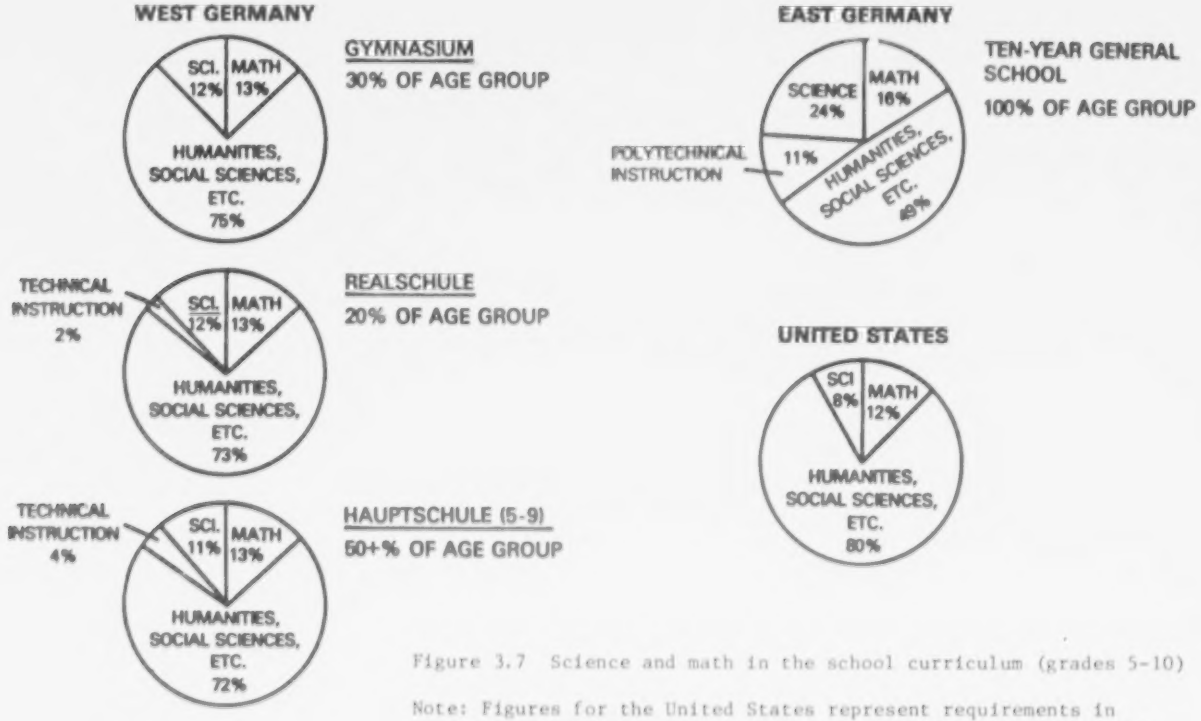

Figure 3.7 Science and math in the school curriculum (grades 5-10)

Note: Figures for the United States represent requirements in approximately 50% of states. More science and math are required in some 20% of the states, while 30% require less.

Gymnasium. Although the number of hours of mathematics instruction per week is the same in all schools, the levels of attainment are different.[35] By the end of the ninth grade, for example, the typical Hauptschule graduate has studied elementary algebra and some basic concepts of plane and solid geometry; students who have completed the tenth grade of the Realschule have studied algebra, plane and solid geometry, trigonometry, and statistics; and students in the Gymnasium have had more rigorous instruction in the same topic areas.

Communist educators contend that learning mathematics aids youngsters in overcoming their fear of science. In the GDR, this conviction is parlayed into an hour of daily mathematics instruction over ten years (grades one through ten) in a uniform program for all children. Basic arithmetic in the first five years is integrated with geometry, which is introduced to the second grade. Plane geometry is taught in the sixth grade, and solid geometry in the seventh, eighth, and tenth grades. Algebra is introduced in the sixth grade, and emphasized in grades seven, eight, and nine. Use of the slide rule is taught in the seventh grade, and its use is integrated into all subsequent science and mathematics courses. Exponential and logarithmic functions and use of mathematics tables are taught in the ninth grade, and trigonometry is the subject of tenth grade mathematics.[36]

SUMMARY

Whenever I have asked educators in either East or West Germany about the heavy emphasis on science in their secondary schools, the universal response has been that it is a fundamental means of achieving scientific literacy so that all their citizens can function effectively in their various roles in a technologically complex and competitive world.

In contrast to the United States, where the approach to science instruction is typically that of studying one science more intensively for a year, in both Germanies, an array of sciences are taught over several years. Also, in both East and West Germany, mathematics, biology, physics, and chemistry are required throughout the compulsory education period, whereas in the United States, beyond the minimum requirements for graduation from high school, science and mathematics study is elective. Technical instruction plays a significant role in general education in the GDR and other Communist countries. It plays a much smaller role in the West German Hauptschule and Realschule, and appears to be absent in the curriculum of West Germany's academic secondary schools. Technical instruction of this kind is also largely absent from U.S. school curricula.

In both Germanies, the length of the school year is about 210 days, and school is in session between thirty and thirty-six hours each week. The total instruction time is, therefore, comparable, about thirty days longer than in the United States. The curricular

emphases, however, are different in the two Germanies. In the GDR, about half the total instruction time is devoted to the natural sciences, mathematics, and technical studies, whereas in West Germany, instruction in these areas accounts for approximately one-fourth of the total curriculum. East German teenagers spend about 24 percent of their time learning science, compared to 11 or 12 percent in the Federal Republic, and 8 percent in the United States. Mathematics study comprises about 16 percent of the East German school curriculum, 13 percent in West Germany, and 12 percent in the United States.

Given the breadth and depth of the program for science education in the GDR, as well as the mathematics and technical programs that support science learning, it is obvious that the GDR is doing a far better job than the United States in providing all young people with a scientific basis for understanding the technological age in which we live. Compared to their American counterparts, East German teenagers spend about triple the time learning science and a third more time learning mathematics in a curriculum that balances theoretical learning with the application of theory in industry and agriculture.

The variation in West German schools makes it more difficult to compare the overall science and mathematics literacy of teenagers in the FRG and the United States. However, given the greater homogeneity of West German society, the nationally developed guidelines, the firmer control that the states have over science and mathematics requirements, and the actual hours of required high school science and mathematics, one must conclude that the West Germans are also doing a better job in providing most young people with a basis for understanding science.

Finally, the scope and depth of the program of study in East German general schools and the West German Gymnasien assures that the 10 to 12 percent of students who go on to the universities have a good understanding of physics, chemistry, botany, zoology, and mathematics, including calculus. Since universities are the training places of future leaders, the approach to preuniversity education in both Germanies assures that all senior officials in government, business, and industry will have an understanding of science that matches the needs of leadership in an era of rapidly expanding technologies.

NOTES

1. Statistical Pocket Book of the German Democratic Republic, 1980 (Berlin: Staatsverlag der Deutschen Demokratischen Republik, 1980), p. 11.

2. U.S. Department of State, Background Notes: German

Democratic Republic (Washington, D.C.: Government Printing Office, 1981), p. 6.

3. Karl Marx (1818-1883) and V.I. Lenin (1870-1924). According to Marxist-Leninist theory, human culture evolves through a succession of stages from Primitive-communal, through Slave-owning, Feudal, Capitalist, and Socialist to Communist. Contemporary "Communist" societies which consider themselves to be in an advanced stage of Socialism are: Bulgaria, Czechoslovakia, the German Democratic Republic, Hungary, Poland, Romania, and the Soviet Union. For purposes of this overview, the words "Communist" and "Socialist" will be used interchangeably.

4. Two groups of children, both comparatively small in number, are not educated in these schools; they are (1) students who attend special schools for the physically and mentally handicapped and (2) students who attend specialized schools in art, music, sports, science and mathematics, or languages, etc., because they have exceptional talent. Statistical Pocket Book, 1980, p. 96.

5. GDR, Council of Ministers, The Ministry of Education, Act on the Integrated Socialist Educational System of the German Democratic Republic (Berlin: Staatsverlage der Deutschen Demokratischen Republik, 1972), p. 37.

6. Marx and Engels, Concerning Education and Training (Berlin: n.p., 1961), p. 162, quoted in Heinz Frankiewicz and others, Paedagogische Enzyklopedie, II (Berlin: VEB Deutscher Verlag der Wissenschaften, 1963), p. 731.

7. Heinz Frankiewicz, Technik und Bildung in der Schule der DDR (Berlin: Volk und Wissen Volkseigener Verlag, 1968), pp. 50-53.

8. Ibid., p. 57.

9. Statistical Pocket Book, 1980, pp. 98-100.

10. Kurt Haspas, Methodik des Physikunterrichts (Berlin: Volk und Wissen Volkseigener Verlag, 1974), p. 29.

11. Haspas, op. cit., 87-89.

12. Siegfried Baer and Rudi Slomma, Lehrerausbildung und Lehrerweiterbildung in der DDR (Berlin: Ministerium fuer Volksbidung in der DDR und der UNESCO-Kommission der DDR, 1973), pp. 15-19.

13. Information obtained during discussion with Prof. Dr. Hansjoachim Lechner at the Humboldt University East Berlin, November 1982.

14. Information for this section was gathered during a tour of East German universities in November 1982 which included discussions with educational administrators, university instructors,

and graduate students, and parents of teenagers in the GDR.

15. Philip J. Hilts, "A Big Military Seems to Mean Less Spending on the Sciences," Washington Post, May 31, 1983.

16. Secretariat of the Standing Conference of Ministers of Education of the States of the Federal Republic of Germany, The Educational System in the Federal Republic of Germany (New York: College Entrance Examination Board, 1979), p. 6.

17. Dietmar Bolscho, Lehrplaene zum Sachunterricht (Kiel: Institut fuer die Paedagogik der Naturwissenschaften, 1978), p. 11.

18. Information, 15, Public Document (Bonn: Press and Information Office of the Government of the Federal Republic of Germany, 1980).

19. Ibid.

20. Secretariat of the Standing Conference, pp. 9-10.

21. Information, 15.

22. John Dornberg, "Outward Calm Belies Youth Discontent," International Herald Tribune, April 1979, p. 9S.

23. Wolfgang Buender and Karl Frey. Discipline-related Curriculum Studies as Part of the Study Course for Science Teachers of Grade 5-13 at the Universities in the Federal Republic of Germany. Institute fuer die Paedogik der Naturwissenschaften (IPN) Report in Brief, #21. Kiel, 1980.

24. Ibid., pp. 21-23.

25. Ibid., pp. 30-31.

26. Herr Boehls, The German School, Potomac, Maryland, February 1983, personal communication.

27. Herr Hauser, Labor Counselor, Embassy of the Federal Republic of Germany, Washington, D.C., February 1983, personal communication.

28. Bolscho, pp. 9-27.

29. For present purposes, science education in the upper secondary level of the Gymnasium (grades 11-13) will not be considered. Information in the following pages is based on data provided by the Institute for Science Education, Christian-Albrechts University, Kiel.

30. Ulrike Skaumal and Lothar Staeck, Die Biologielehrplaene fuer die Sekundarstufe I, 1980 (Kiel: Institut fuer die Paedagogik der Naturwissenschaften, 1980), pp. 9-222.

31. Michael Koehne, Die Physiklehrplaene fuer die Sekundarstufe I (Kiel: Institut fuer die Paedagogik der Naturwissenschaften, 1979), pp. 5-180.

32. Peter Kriesel, Die Chemielehrplaene fuer die Sekundarstufe I (Kiel: Institut fuer die Paedagogik der Naturwissenschaften, 1979), pp. 9-193.

33. The discussion in this section is based on Dr. Lore Hoffmann, "Consequences for Science Education based on the results of Girls' Learning Interest," in Contributions Girls and Science And Technology (GASAT)-Conference 1981, pp. 123-44, Eindhoven, the Netherlands.

34. Iris R. Weiss, Report of the 1977 National Survey of Science, Mathematics, and Social Studies Education (North Carolina: Research Triangle Park, 1978), p. 24.

35. Discussions with science and mathematics teachers and review of mathematics textbooks, The German School, Potomac, Maryland, November and December, 1981.

36. Neuner, pp. 153-58.

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Charles P. McFadden

4. Science Education in the USSR

Since Sputnik I gave impetus to curriculum reform in the United States and other countries, education in the Soviet Union has not marked time. An analogous period of science and mathematics renovation in the USSR, beginning in the late 1960s, has brought about remarkable results there, notwithstanding some familiar problems. In fact, the level of education in mathematics and science of all students in the USSR is very high. The National Science Foundation-Department of Education report2 on science and engineering education in the United States, which noted a widening gap between the level of science and mathematics training and skill acquired in U.S. schools by those interested in science and engineering careers and those who are not, points out that "in the Soviet Union, there are national elementary and secondary curricula in science and mathematics which, in content and scope, surpass that of any other country." The significance of this conclusion is magnified considerably by the achievement in recent years in the USSR of virtually universal complete secondary education, which in the case of all students includes the full curriculum in science and mathematics.

A comparative account of Soviet science and mathematics education given by Wirszup3 concludes that "the disparity between the level of training in science and mathematics for an average Soviet skilled worker or military recruit and that of a non-college-bound American high school graduate, an average worker in one of our major industries, or an average member of our all-volunteer Army is so great that comparisons are meaningless."

FEATURES OF SOVIET EDUCATION

Before appraising the education in science given by Soviet schools, an observer must first unravel the main structural and pedagogical particularities of the Soviet system of education. For instance, elementary education, characterized by one teacher for all subjects, spans only three years in the USSR. It is followed by seven years of secondary education, characterized by specialist teachers for each subject. This long period of secondary education, together with other factors, more than offsets the apparent

compression from twelve years of general education, characteristic of North American schools, to the ten years of general education in the USSR. One of these other factors is the age of school enrollment. Soviet children begin school only after reaching their seventh birthday, nearly a year later than children in the United States and Canada. On the other hand, most have attended kindergartens from three to seven years of age, where they "are taught to read and do simple sums."[4] Another factor is the subject matter preparation of the secondary teachers, which in most cases includes an education in the subject taught to a level which equates to a Master's degree in North America.

The constitution of the USSR adopted in October 1977 mandates "the institution of universal, compulsory secondary education."[5] In 1979, 99.6 percent of the graduates of the eighth class proceeded to the final two years of secondary education,[6] the majority of these in ten-year general education schools, the remainder in schools which, by prolonging secondary education for an additional one or two years, combine the final years of general education with specialized education or vocational training. The extent to which the USSR has achieved complete secondary education is indicated in the Soviet report of the thirty-seventh session of the International Conference in Education of the United Nations Educational, Scientific, and Cultural Organization (UNESCO):[7] "In 1978 over 5 million boys and girls, that is, about 97.7 percent of the number of the first graders of the respective age, received complete secondary education." Among the working population, 543 of every 1,000 workers had attained at least a complete secondary education by 1978, including 111 with higher education. The comparable figures for 1970 were 342 and 78, indicating a remarkably rapid increase in the average level of education of the working population of the USSR over this period of time.[8] The structure of education in the USSR is represented in Figure 4.1.

School legislation in the USSR provides for a "basically uniform content and level of general education on the entire territory of the USSR, with all-round consideration for the national features of the population in the Union Republics."[9] Except for some aspects of instruction in language, literature, and social science, this in practice means that all students throughout the USSR study the same subjects and are provided the same textbooks, albeit in over sixty different languages. There is also a common examination of all students after the eighth and tenth years. The prescribed syllabus is summarized in Table 4.1.

A characteristic feature of Soviet education, embodied in the syllabus, is the application of the polytechnical principle. In contrast to a monotechnical education, as perhaps exemplified by secondary vocational schools in North America and the vocational streams within our high schools, the intent of a Soviet polytechnical education is to open up to young people the prospect and opportunity of entering any profession they may subsequently choose, including those which require a higher education. It is also an intention to develop an understanding and respect for all those who work, to

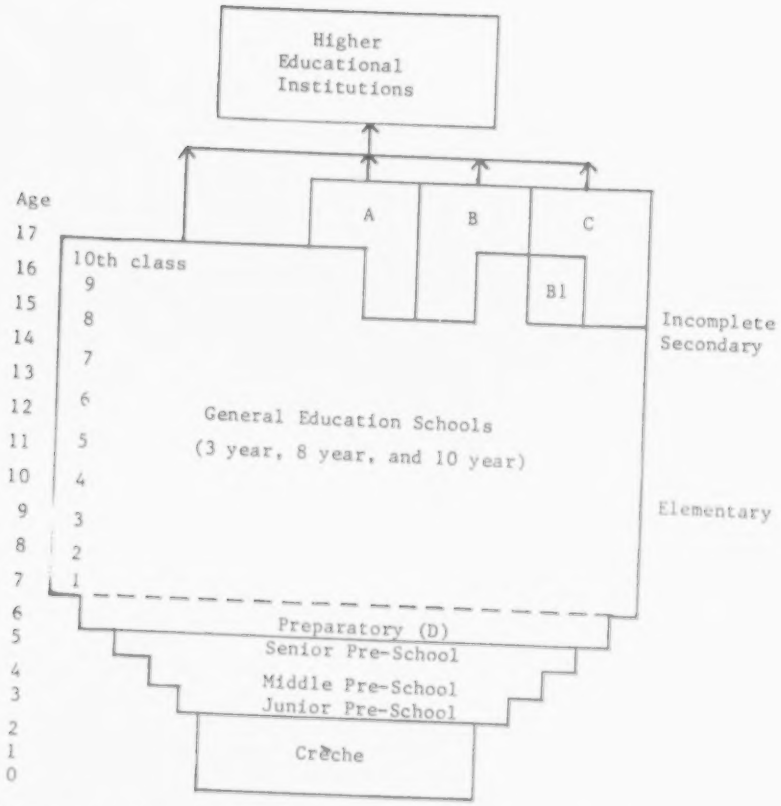

Figure 4.1 Unified educational system of the Soviet Union

Notes: A represents specialized secondary schools, which include complete secondary education plus specialized training.

B represents vocational schools, which include secondary education except for a diminishing number (B1) whose graduates must complete this level at evening or correspondence schools.

C represents evening or correspondence schools, which offer the final two years of secondary education to workers with an incomplete secondary education.

D : The preparatory year is being incorporated into the general education school. The results of this incorporation will be an 11-year general education school.

TABLE 4.1
Syllabus for Soviet general education schools

Subjects	Number of periods per week by grade										
	1	2	3	4	5	6	7	8	9	10	Total
Russian language	12	10	10	6	6	3	3	2	–	2/0	53
Literature	–	–	–	2	2	2	2	3	4	3	18
Mathematics	6	6	6	6	6	6	6	6	5	5	58
History	–	–	–	2	2	2	2	3	4	3	18
Fundamentals of Soviet state structure and law	–	–	–	–	–	–	–	1	–	–	1
Social science	–	–	–	–	–	–	–	–	–	2	2
Nature study	–	2	2	2	–	–	–	–	–	–	6
Geography[a]	–	–	–	–	2	3	2	2	2	–	11
Biology	–	–	–	–	2	2	2	2	0/2	2	11
Physics	–	–	–	–	–	2	2	3	4	5	16
Astronomy	–	–	–	–	–	–	–	–	–	1	1
Mechanical drawing	–	–	–	–	–	1	1	1	–	–	3
Chemistry	–	–	–	–	–	–	2	2	3	3	10
Foreign language	–	–	–	–	4	3	3	2	2	2	10
Fine art	1	1	1	1	1	1	–	–	–	–	6
Singing & music appreciation	1	1	1	1	1	1	1	–	–	–	7
Physical education	2	2	2	2	2	2	2	2	2	2	20
Labour education	2	2	2	4	4	4	4	4	4	4	34

Total periods of compulsory subjects per week	24	24	25	26	32	32	32	33	32	32	291
Electives	-	-	-	-	-	-	2	4	6	6	18

Source: Adapted from Zimin, P.V., "The Soviet School System," in Education in the USSR, N. Kuzin and M. Kandakov, eds., Moscow, Progress Publishers, 1977, p. 45; updated to include an increase in the number of hours of workshop training mandated in 1980, as given in L.F. Koleznikov and V.N. Turchenko, Nekotorye problemy dal'neshego rasvitiia srednego obrazovannia [Some problems of further development of secondary education], Sovetskaia Pedagogica, 1980, vol. 6, p. 27.

[a]Geology, which is not taught as a separate school subject, except as an option, is included in the five-year course in geography.

introduce the main branches of production to all students and to acquaint each student with at least some aspects of productive labor. The overall aim is to link the school with productive work, to connect the knowledge and skills gained in school with their utility -- in a word, to link education with life.[10]

A specific consequence of the polytechnical principle is the balance between mathematics and natural science, on the one hand, and humanities and the social sciences, on the other, each of which take up somewhat more than 40 percent of instructional time. In comparison with North American schools, the major difference is the amount of attention given by all students to the study of mathematics and the natural sciences, most notably physics. Of course, the purposeful application of the polytechnical principle is also reflected in the content of the courses.

Typically -- that is, in three cases out of four -- a Soviet student attends a school which contains all ten grades. There are, however, particularly in rural areas, also elementary schools (years one to three only) and eight-year schools (years one to eight). The typical ten-year school draws a student body of about 750 from the immediate district and is staffed by about fifty teachers, including a principal and three vice-principals. In addition, it will have from one to three laboratory assistants, a full-time doctor, a full-time dentist, and a sizeable maintenance staff, making a total staff of about sixty-five.

THE CONTENT OF THE SCIENCE COURSES

The Soviet child's formal study of science begins with nature study, which is separated from the reading program as an independent subject after the first year of school. Two periods per week in each of the second, third, and fourth years are assigned to it. The ascribed aims of the course include the development of observation skills, inquisitiveness, and a love of nature.[11]

The study of science begins in earnest in the fifth year of school with two periods per week of biology. It is taught by a specialist teacher in a lab-classroom which invariably includes an abundance of growing plants and a collection of stuffed animals. Botany is taught in the fifth and the first half of the sixth year, followed by zoology in the latter half of the sixth year and all of the seventh year. In the eighth year the subject matter is anatomy. General biology is taught in the final two years, including the theory of evolution in the ninth and cytology, ecology, genetics, and bio-chemistry in the tenth year.

The current Soviet biology curriculum is the result of a reform which aimed to modernize substantially its content, particularly by increasing its theoretical level. The change appears, in this respect, to be comparable to that brought about in North America by the Biological Sciences Curriculum Study. The new Soviet biology curriculum includes an elaboration of the concept of ecology and

theme of the biosphere, with the aim of "placing the question of the protection of nature on a scientific basis." It also gives systematic attention to revealing the "historical growth of the organic world," and to "unveiling the material basis of the phenomena of heredity, variability and ontogenesis."12

Instruction in chemistry begins in the seventh year of school with attention to acidity, electrovalence, and classes of bonding. From the very beginning, the study of chemistry rests on atomic theory. In the eighth year, students are acquainted with the periodic table and the electronic structure of the atom. Special attention is given to the halogens and the first group in the periodic table. In the ninth year, the study of inorganic chemistry is completed, beginning with the theory of electrolytic dissociation and finishing with a study of all the metals. In the tenth year, attention is given over completely to the study of organic chemistry, including biochemistry.

The two features which appear to unite the Soviet curriculum in chemistry are its presentation on the basis of contemporary physical theory, including the structure of the atom and kinetic-molecular theory, and the consistent attention to technological applications. The former emphasis was given by the recent curriculum reform, but unlike the reform in North America, this emphasis does not appear to have displaced attention to applications.

An 1980 article by one of the USSR's leading chemical educators, D.A. Epshtein,[13] is indicative of the importance of the polytechnical principle in shaping the Soviet chemistry curriculum. In particular, noting the importance of the rates of chemical reactions to the chemical industry, he argues that this fact is not yet fully mirrored in the course in chemistry, necessitating significant modifications in the direction of uniting the inorganic and organic courses on the basis of physical chemistry. Without detailing the various proposals he advances for improving the Soviet chemistry curriculum, the important fact which his article exemplifies is the persistent attention given by Soviet educators to unifying instruction in the various science disciplines on the basis of the simplifying generalizations of modern science and strengthening the connection between education and productive labor.

One consequence of the application of the polytechnical principle to the design of the Soviet school curriculum is the attention given to physics. As the science embodying the main principles impelling the scientific-technological revolution, physics, not surprisingly, is allotted sixteen course hours over five years, more than is allotted to any other natural science, and comparable to history, literature, and foreign language. The contrast between the physics education of Soviet students and that of North American students is more striking than in any other subject.

The physics course begins in the sixth year of the Soviet school with an introduction to the molecular structure of matter, introductory mechanics, and hydro- and aerostatics. In the seventh

year, the students study heat phenomena, including heat transfer, changes of state, and heat engines; and electricity, including the structure of the atom, electrical circuits, work done by an electrical current, and electromagnetic phenomena. In the eighth year, they return to the study of mechanics, systematically studying kinematics, dynamics, equilibrium, and the conservation laws. Likewise, in the ninth year, they return to both heat phenomena and electrodynamics, systematically studying molecular physics, thermodynamics, the kinetic molecular theory of an ideal gas, mutual transformations of liquids and gases, surface tension of liquids, thermal expansion of solids and liquids, electrostatics, direct current electricity, electrical current in various media, the magnetic pole associated with currents, electromagnetic induction, and magnetic properties of matter. In the tenth year, Soviet students study oscillations and waves, including mechanical oscillations, electromagnetic oscillations, the production, transformation, and use of electrical energy, mechanical waves, sound, and electromagnetic waves. This is followed by the study of optics, including geometrical optics, light waves, the basics of the theory of relativity, radiation and spectra, and light quanta and the photoelectric effect. Finally, the study of physics in the tenth year concludes with atomic and nuclear physics, including atomic physics, physics of the atomic nucleus, and elementary particles.

As is the case in all science classes, physics is taught in a lab-classroom. Adjoining it is a storage room with a universally mandated provision of equipment sufficient for students to work in pairs in the approximately twenty experiments presented for each year of the physics course. There is also a standard provision of carefully designed demonstration equipment as well as relatively sophisticated equipment for the independent work which students do at the end of each of the eighth, ninth, and tenth years.

As is discussed at greater length in the next chapter, the curriculum reform of the late sixties and early seventies in the USSR particularly concerned mathematics. In the early 1950s, arithmetic (years one to six), algebra (years six to ten), geometry (years six to ten), and trigonometry (years nine and ten) were taught as separate subjects. To free time for introductory calculus and linear programming in the senior classes, mathematics education was substantially reformed in 1967, principally in the direction of introducing algebraic and geometric ideas at an earlier age, but also by changes in approach.

The new name of the elementary course, a change from "arithmetic" to "mathematics," reflects the intention of more closely linking arithmetic and algebra. The first three years focus on an introduction to numbers, measurement, and simple fractions, with an emphasis on doing problems orally. Algebraic ideas and geometrical material are studied from the fourth year, when formulas and equations, percents, positive and negative numbers, coordinates and graphs, the notion of a function, and geometrical transformations and symmetry are introduced. In the seventh year elements of vector algebra are taught and in the eighth, the coordinates of a vector are

considered. This knowledge is directly applied that year in the physics course. Also in the eighth year, exponential, logarithmic, and trigonometric functions are introduced.

Although the new content is to be left in place, the approach has recently been characterized as excessively abstract and is being held responsible for a noticeable drop in the mathematical knowledge and interest of Soviet school graduates. I was referred in the USSR to an article by Academician Pontriagin[14] which advances this critical view. Significantly, his article was published with a supportive editorial commentary in the theoretical journal of the Communist Party of the Soviet Union after the editors had first consulted extensively with leading mathematicians, educational scientists, and teachers. It is emphasized in the article and the editorial commentary, however, that there is no intention to retreat from the impressive content of Soviet school education in mathematics, which includes, in the final two years, mathematical induction; elements of probability; series and limits; trigonometric, logarithmic, and exponential functions; integral and differential notions; stereometry; vectors; coordinate geometry; and polar coordinates.

The Soviet economist and educator Turchenko has described the recent changes in the content and methods of instruction in education as the beginning of a second revolution in Soviet education.[15] According to Turchenko, the first, attendant on the revolutionary transformation of society as a whole within the territory of the USSR, gave rise during a period of turbulent experimentation to a unified, labor, polytechnical, secular school and entailed a massive expansion of public education, beginning with the enrollment of only a minority of youth in elementary schools before 1917 and reaching universal complete secondary education by 1978. With respect to school management, new forms emerged, including the role of the student collective[16] and of the pedagogical council.[17] Of course, this first revolution in education concerned not only its extent and forms of organizations, but also its political goals and its content, particularly in the social sciences. Consequences for the content of natural science education included the focus noted above on the concept of evolution in the study of biology and a conscious effort to develop an atheistic world outlook in connection with the study of physical laws of cause and effect.

The second revolution, according to Turchenko, began in the latter part of the 1960s in the USSR. "By 1975 the introduction of new teaching programs and curricula for all subjects had been completed; methods of teaching are being thoroughly renovated and diversified; and contemporary teaching aids are being much more widely and effectively employed."[18]

This revolution in education, Turchenko argues, is necessitated, in both socialist and capitalist countries, by the revolution in science and technology. Competition in the field of education, in his view, has shifted from the qualitative to the quantitative side, to "a competition for the most rapid and fullest implementation of a revolution in education."[19] This revolution will continue through

the next few decades and includes the "actualization of the content of education," by which Turchenko means, in part, "adjusting its scientific content to the dynamic structure of contemporary scientific knowledge" and, in part, making "socio-productive activity," including research and design activity by students, "an inseparable part of the activity of educational institutions." This revolution also includes the "introduction of teaching machines, optimization of the flow of information, introduction of forms of division and coordination of pedagogical labor that are new in principle and are connected with the concentration of the school, and a transition to education from early childhood (and perhaps infancy)."[20]

THE IMPROVEMENT OF CURRICULUM AND TEACHING

Figure 4.2 graphically illustrates the organizational framework for curriculum improvement in the USSR. Scientists, including those in research institutes and at higher educational establishments, are united by the USSR Academy of Sciences, educational researchers by the USSR Academy of Pedagogical Sciences, and teachers by the USSR Ministry of Education. All are linked by commissions formed to improve instruction in the various school subjects and by the publication, in both scientific and educational journals and magazines, of the drafts of any program changes proposed by these commissions.

Of the fourteen institutes of the USSR Academy of Pedagogical Sciences, that with the most direct responsibility for science education is the Research Institute for Content and Methods of Instruction. In turn, this Institute is subdivided into a number of laboratories, including separate laboratories for each school subject and various laboratories concerned with interdisciplinary issues pertaining to the content and methods of instruction. These laboratories conduct research, train graduate students, prepare books on methodology for teachers, and produce various learning resources, books, and aids for both students and teachers. They also have the main practical responsibility for reform of curriculum and teaching methods. The USSR science and mathematics education specialists are found in the laboratories of this Institute and among the countrywide network of researchers which it coordinates.

When the draft of a new program in a school subject has been prepared by the appropriate commission, it is published and discussed in the pages of the teachers' journal for that subject as well as in journals for scientists in that field. Revisions are then made on the basis of the discussion and a textbook writing competition is held. Two or three variants are tried out in the schools for one to three years before one of them is adopted by the Ministry of Education for countrywide use.

The textbooks, which are comparable to newsprint in textural quality but are hardbound, are now distributed free of charge to the students. (In previous years they were sold for about $ 0.50 each.) Annual publication also means annual revisions, corrections,

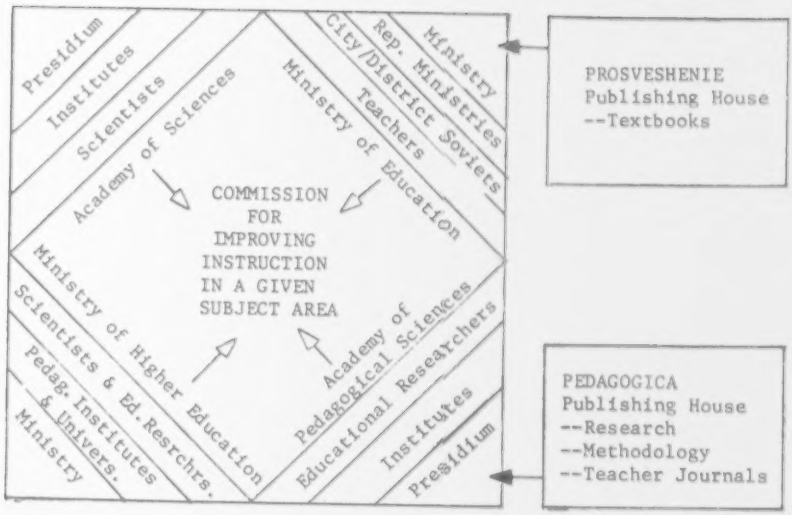

Figure 4.2 Structure of research, development, and implementation in Soviet education

additions, and updating; major program changes occur less frequently.

One of the problems currently given major attention at the Research Institute of Content and Methods of Instruction is the interconnection between subjects in the curriculum; in particular, the problem that the unity of the world be comprehended in the course of study of different subjects. When I pointed out that some educators in the West favored combining instruction in the sciences, Dr. I.S. Matrusov, Deputy Director of the Institute, responded that Soviet educators disagree with this approach. They are looking at what is common to several or all areas of study so that common points may be given mutually supportive attention.

THE TEACHERS

Of course, no amount of attention to curriculum can by itself guarantee that progress will take place in the classroom. The teacher's qualifications, workload, and dedication are vital factors determining the outcome.

The melioration of the teaching force in the USSR is an ongoing process, but current data are already impressive. For example, the teacher/student ratio reported in official statistics has shown a steady improvement and is now nearly one teacher for every sixteen students. This figure, however, understates the reality, particularly in science, which benefits from full-time laboratory assistants. The actual teaching force also includes the paid professionals who staff the extensive extramural educational activities and provide most of the optional courses senior students are required to take. It also includes those professionals engaged in productive labor who work with the students in connection with the labor education component of their studies. If these factors are taken into account, the actual ratio in terms of full-time equivalent teachers must be closer to one teacher per twelve students, particularly in the senior grades.

The normal teaching load is eighteen periods per week. However, for proportionately higher salaries, teachers may teach up to twenty-four periods. The usual class size is thirty to thirty-five students. This class, however, is broken down into three sections of ten to twelve students for foreign language instruction. The rather large size of the usual class does not appear to place the teacher under the kind of strain that teachers experience with large classes here. This observation can partly be explained by the self-discipline of the students and the omnipresence of teaching assistants who set up, take down, and maintain laboratory and demonstration equipment and who operate the lavishly provided audiovisual aids, including projectors for films and filmstrips, tape recorders and, increasingly, television sets.

All Soviet teachers in grades four and beyond are specialists, licensed to teach only those subjects for which they have obtained suitable academic qualifications. In 1979, nearly 90 percent of

these teachers had a complete higher education. In 1975 the comparable figure had been 82 percent.21 The remainder, along with the majority of teachers of the elementary grades, are graduates of specialized secondary schools for training teachers.

The Soviet designation of teacher education schools as secondary rather than higher educational institutions might be misleading. In fact, I believe an objective assessment of the qualifications of North American teachers would place most at a level comparable to Soviet so-called "specialized secondary" education and only a minority at a level comparable to Soviet graduates of pedagogical institutes and universities. Indeed, the academic preparation of the 90 percent of Soviet secondary teachers who have completed higher education is the same as that of the majority of the USSR's research scientists and scholars. Course content is prescribed for each discipline and is the same throughout all higher educational institutions in the USSR. The one significant difference is the requirement that graduates of pedagogical institutes teach for three years.

Consider, for example, the requirements for a future teacher of physics and astronomy. The following data are taken from the plan of studies for this specialty at Moscow State Pedagogical Institute. Presumably, the program in physics at the University of Moscow and at any other higher educational institution would be the same.

The complete program spans five years, requiring attendance for forty-two weeks each year and including thirty-five weeks of theoretical instruction and seven weeks of examination in each of the first three years. In the summer after the third year, students have four weeks of practice teaching at a summer camp. During the fourth year, the amount of theoretical instruction is reduced to allow for six weeks of practice teaching, and during the final year, there are twenty-four weeks of theoretical instruction and four weeks of examination, allowing for eight weeks for practice teaching and six weeks for work on a diploma project. The latter ensures that all prospective teachers have some research experience. The successful defense of the diploma project is a requirement for graduation and appears, from conversations I had, to have more prominence in practice than the six weeks allotted to it would suggest.

The allocation of hours of instruction to the various courses which future physics teachers must complete is shown in Table 4.2. The specific information for physics agrees with Kashutin's information on the percentage of instructional time devoted to the various components of the syllabi for all specializations.22 According to his data, 60-65 percent of instructional time is devoted to the major and minor subjects; 20-23 percent to psychology and pedagogy, including teaching methods and practice teaching; 10-11 percent to socioeconomic subjects; and 5-6 percent to general education subjects.

Improvement of instruction requires an effective system of in-service education. The provision for this in the USSR is

TABLE 4.2
Program of studies for intending physics teachers in the Soviet Union

Course	Hours of Instruction: Lectures & Seminars	Hours of Instruction: Practical Studies & Labs	Semesters When Taught	Percent of Total
History of CPSU	170	--	1,2,3	
Marxist-Leninist philosophy	140	--	3,4,5,6	
Political economy	140	--	6,7	
Scientific Communism	80	--	8,9	
Basis of scientific atheism	24	--	7	
Soviet law	30	--	8	
				12
Introduction to the specialty	36	--	1	
Physiology of growth and school hygiene	42	8	2	
Pedagogy (including history of pedagogy)	100	50	3,4,5	
General & educational psychology	74	26	3,4	
Methods of teaching physics	40	110	6,7,8	
Practicum in the solution of physics problems	--	110	9	
Methods of teaching astronomy	10	20	8	
				13
Foreign language	240	--	1,2,3,4	
				5
Mathematical analysis	220	180	1,2,3	
Analytical geometry	80	80	1,2	
Methods of mathematical physics	36	14	4	
Numerical analysis & programming	35	35	6	
				14

General physics	300	530	1,2,3,4,5	
Theoretical mechanics	54	36	5	
Electrodynamics	70	30	6	
Theory of relativity	24	24	7	
Quantum mechanics	60	60	7,8	
Statistical physics & thermodynamics	50	40	8,9	
Electron theory	40	30	9	
Nuclear physics	24	12	10	
General astronomy	140	70	5,6	
Basis of cosmonautics & physics of cosmos	48	12	6,7	
Astrophysics	110	120	8,9,10	
				38
Technology of materials, practice in educational skills & safety techniques	30	80	4,5	
Technical means of instruction	20	30	4,5	
				3
Radiotechnology	50	80	7,8	
Electrotechnology	60	30	7,8	
				5
Elective courses	260	170	7,8,9,10	9
Physical education		140	1,2,3,4	3

apparently massive and thorough. It includes the requirement of a refresher course at least once every five years as well as periodic seminars and conferences, including weekly meetings. These are supported by a network of 187 institutes for improving instruction and 4,500 regional, city, and district methodological centers employing 12,000 methodologists and enrolling nearly one million teachers at any one time. Another indication of the extent of teacher commitment to professional development is the publication and sale in 1975 alone of 157 new books on teaching methods -- over 14 million copies.[23]

The most important links in the system of improving instruction are the principals and vice-principals, whose main duty, I was invariably informed in response to my questions, is to assist in improving teaching methods. Insuring their continued identification with the teachers, principals teach six periods per week while vice-principals teach for twelve periods. Apparently, they are able to devote most of their remaining time to educational leadership, including an extensive schedule of visits to observe teaching. Relations between principals and staff seemed friendly, without fear or formalism.

EXTRAMURAL STUDIES

No account of Soviet science education would be complete without consideration of the various ways the educational system attends to the special interests and abilities of individual students, including those inclined toward science and mathematics. Taken together, optional courses and the various forms of extramural education constitute an extensive second tier of educational provision, counterbalancing the set (or core) school curriculum and its requirement that all students receive the same content and level of instruction.

In the first place, the second tier includes optional courses in the seventh through tenth years of school. Rather than advancing the level of the students' knowledge of school subjects, these courses include subjects not on the school curriculum as well as the application and enrichment of content featured in school subjects. The aim of providing preprofessional orientation is partly served by these courses. In some cases, a given school will emphasize a particular area of specialization. For example, I visited one school in Moscow which emphasized computer technology and computer programming in its optional courses; the school housed the computer of a large geophysical exploration enterprise whose engineers and technicians taught the optional courses.

Receiving worldwide attention have been the special math-physics schools attached to several universities. One of these is the math-physics school attached to the University of Novosibirsk in Academic City, the hometown of the Siberian Branch of the USSR Academy of Sciences. Students enroll at this school after their eighth or ninth year of schooling on the basis of competition. The

first round of the competition is a written examination. The second is a series of interviews by scientists and the final round is a summer science camp of several weeks duration, held on the University of Novosibirsk campus. Students from major university and scientific centers and from professional homes are not eligible, it being considered that such students already have adequate opportunities. Rather, I was told, students from remote villages, large families, and worker or farmer parents are favored for admission, the aim being to develop talent that might otherwise be bypassed. At the special math-physics school, the students attend special lectures as well as complete the normal curriculum. They also spend one day each week working in scientific research at one of the Institutes of the Siberian Branch of the USSR Academy of Sciences. Most of their teachers are active scientists and many are professors at Novosibirsk University.

It should be emphasized, however, that opportunities for intensive education in the natural sciences of the kind featured at the special math-science schools are by no means confined to these schools. Correspondence courses, interest groups, science fairs, summer science camps, and other extramural activities conducted by professional scientists are common everywhere and widely available to interested students. There are also many thousands of young pioneer palaces or other extra-school establishments. These are staffed by paid, fully trained professionals, including scientists. The latter are among the leaders of the science interest clubs, whose members include young children as well as secondary school students and whose activities range from stargazing to Arctic scientific expeditions.

CONCLUSION

Universal complete secondary education in the USSR is an impressive achievement. With respect to the content of this education, only a very small percentage of U.S. eighteen-year-olds have received an education comparable to that of their Soviet age cohort. Less tangible are comparisons in other important outcomes of education. But the impressive second tier of educational provision in the USSR, combined with the current focus of Soviet educators on the development of student creativity, learning skills, and career orientation, cannot be without effect.

It is a truism that today's students are tomorrow's working population. Just as the relative economic achievements of the United States in this century must owe a great deal to the expansion of its educational system, which for many decades set the world pace, so, in turn, it is reasonable to assume that the USSR will derive benefits in the coming decades from its unprecedented attention to education.

NOTES

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8. Kozhevnikov, E., ibid.

9. Fundamentals of Legislation of the USSR and the Union Republics on Public Education, Law of 19 July 1973. Moscow, Novosti Press Agency Publishing House, 1975.

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11. Kuzin, N.P., and M.N. Kolmokova, eds., Sovetskaia shkola na sovremennom etape [The Soviet school in the contemporary period], Moscow, Pedagogica Publishers, 1977, p. 77.

12. Ibid., p. 125. Here and throughout the article, all translations from the original Russian are by the author.

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1980, vol. 14, pp. 99-112.

15. Turchenko, V. The Scientific and Technological Revolution and the Revolution in Education, Moscow, Progress Publishers, 1976.

16. See, for example, Lawler, J., "Collectivity and Individuality in Soviet Educational Theory," Contemporary Educational Psychology, 1980, vol. 5, pp. 163-174.

17. See, for example, Kondakov, M.I., "Education Management in the USSR," in Education in the USSR, N. Kuzon and M. Kondakov, eds., Moscow, Progress Publishers, 1977.

18. Turchenko, p. 63.

19. Ibid., p. 73.

20. Ibid., pp. 171-172.

21. Kozhevnikov, E., p. 6.

22. Kashutin, P.A., "Problems Connected with the Reproduction of Pedagogical Personnel in the USSR," report presented at the Sixth General Conference of the International Association of Universities, Moscow, August, 1975, p. 32.

23. Kuzin and Kolmakova, p. 220.

Izaak Wirszup

5. The Soviet Challenge in Science, Mathematics, and Technology Education

INTRODUCTION

The United States is now facing one of the sternest challenges in its history. On the one hand, the United States is still acknowledged as the world leader in science and technology. We are a nation whose scientific elite has for the past fifty years been in the forefront of research and discovery, whose major universities and training programs are a magnet for students, scholars, and scientists from around the world. America's economic power has converted scientific and technological breakthroughs into top-quality, mass-produced consumer goods and services; its medical achievements have made possible superb health care and offered a model for other countries. The United States has also developed a system of civic education that is among the very finest in the world. Nevertheless, American elementary and secondary education, especially in the areas of science and mathematics, is seriously deficient. While we can take pride in the achievements of a small but superb corps of top-level scientists and engineers, we must acknowledge that this preeminence has been eroding over the last decade, and that most of our population is scientifically illiterate.

Over the past two decades, many industrialized nations, such as Japan and the countries of Western Europe, and even emerging countries, such as Korea and Taiwan, have recorded outstanding achievements in the education of the general population. Since 1966, the Soviet Union, followed by the other Communist-bloc countries, has launched an educational mobilization, adopting general education standards and technical training programs of unmatched quality and magnitude. During this same period, the overall achievement levels of American secondary school graduates have not only failed to rise, but actually plummeted. The same downward trend can be seen in literacy and basic skills, where levels which may have been sufficient for survival years ago are totally inadequate today. In brief, the educational level of the American citizenry is already damaging our economic strength, our competitive edge in technology and production, and our ability to defend ourselves.

THE SOVIET EDUCATIONAL MOBILIZATION

As stated in the previous section, in the past eighteen years the Soviets have made quantitative and qualitative gains without equal in the history of their educational system, gains which affect their entire young population. The major impetus for change was a 1966 resolution adopted by the Communist Party's Central Committee following the Twenty-Third Party Congress. This resolution, entitled "Measures for Further Improving the Work of the Secondary General Education School," addressed the demands of the "scientific and technological revolution" for a skilled labor force with a broader general education and a higher intellectual level. The result was a commitment to new educational goals in relation to manpower needs, with radical curricular reforms and an unexpected emphasis on the individual and the development of his capacity for independent, creative work.

The Soviets had previously been content with a small scientific elite, while the majority of their students remained at lower levels of academic performance. However, a shortage of trained manpower and the introduction of high technology into the Soviet military and related industry demanded workers and soldiers with improved understanding of science and technology. In addition, the Soviets' own studies showed increased productivity from workers who, having received a solid general education, acquired technical training in schools rather than on the job. Research which had already led to notable advances in educational psychology also helped pave the way for the curricular reforms of 1966 and the introduction of compulsory secondary education in 1975.

Explicitly mandated in the new Soviet Constitution, universal secondary education was vigorously pursued in the ninth and tenth five-year plans (1971-80) and has now been accomplished. Between 1975 and 1980 the percentage of students remaining in school from grade one through graduation from a secondary institution climbed from 86 percent to 97 percent.[1]

The Soviets' structural and curricular reforms provide a diversified, multitrack system that keeps students in school through the secondary level (grade 10 or its equivalent) and guides them into courses of study corresponding to their abilities and potential. The 8-year school provides a common educational experience for all Soviet children, who enroll at age 7 and attend 6 days a week. Graduates of the 8-year school then advance along one of several avenues: (1) Those who are strongest academically complete their secondary education in grades 9 and 10 of the general education school. Approximately 50 percent of graduating eighth-graders chose this course in 1982-83. (2) Other academically strong students (some 10 percent of 8-year school graduates) enroll in specialized professional institutions (technicums), where, in addition to receiving a general education, they acquire technical training in areas such as computer programming or production management or learn a profession (e.g., teaching grades 1-3). Admission to these schools is by examination. (3) The remaining students are trained as skilled workers in one of the many types of technical-vocational schools

where they also complete their secondary education (the programs of grades 9 and 10), either in the same school or in a general education evening school. Some 40 percent of 8-year school graduates took this route in 1982-83.

One of the most noteworthy features of this system is that there are no educational dead ends. Every school provides its students with a general education that enables them to continue on to an institution of higher learning.[2]

In 1980, 99.3 percent of 8-year school graduates went on to study in general education day schools, technical-vocational schools, or specialized secondary institutions.[3] To appreciate the scale of the Soviet educational expansion, one need only note that during the Stalin era the secondary school graduation rate was less than 5 percent.[4] Even in 1957, the year of Sputnik, no more than 1,728,000 students graduated from secondary schools.[5] It is easy to see why the Soviets have termed these changes an "educational revolution." The radical curricular reforms are a measure of their national commitment to education in science and technology for all students.

Curricular Reforms

Practically all Soviet young people now complete secondary school or its equivalent and work through extensive compulsory science and mathematics programs.[6] The foremost Soviet scientists, mathematicians, and educators have worked together to improve these curricula and perfect teaching methods in a concerted drive to provide mass education of unsurpassed quality.

Responsibility for the 1966 reform in general education schools was assigned to the highest scientific and educational institutions of the Soviet Union -- the USSR Academy of Sciences and the USSR Academy of Pedagogical Sciences. A team of scholars from both Academies, headed by A.N. Kolmogorov, has led the entire school mathematics reform since 1964.[7] Kolmogorov, one of this century's great mathematicians, worked in close collaboration with such outstanding scholars and educators as A.I. Markushevich, B.V. Gnedenko, V.G. Boltyanskii, N.Ya. Vilenkin, and I.M. Yaglom to set the goals of the new program, design the curriculum in every detail, decide on approaches to various topics, and write the texts and manuals for students and teachers (Kolmogorov himself is co-author and editor of textbooks in geometry -- Geometry 6-8 -- and in algebra and calculus -- Algebra and Elements of Calculus 9-10). The new curriculum has drawn extensively on the extraordinary Soviet research in the psychology and methods of learning and teaching mathematics.

The result of this 18-year effort is a mathematics program that is modern in content, innovative in approach, well-integrated, and highly sophisticated. The curriculum gives strong emphasis to theoretical foundations and logical rigor as well as to applications. The outline of the curriculum for grades 4-10 follows. In quality, scope, and range of implementation, I believe that it surpasses that of any other country.

Outline of the 1982-83 Soviet Mathematics
Curriculum for Grades 4-10

GRADE 4

Mathematics (6 hours a week; total: 204 hours)

I. Natural numbers (40 hours)
II. Arithmetic operations with natural numbers (50 hours)
III. Common fractions (15 hours)
IV. Decimals (80 hours)
V. Review; problem solving (19 hours)

GRADE 5

Mathematics (6 hours a week; total: 204 hours)

I. Positive and negative numbers (25 hours)
II. Arithmetic operations with positive and negative numbers (70 hours)
III. Rational numbers (25 hours)
IV. Arithmetic operations with rational numbers (65 hours)
V. Review; problem solving (19 hours)

GRADE 6

Algebra and Geometry (6 hours a week; total: 204 hours)
Algebra (4 hours a week; total: 136 hours)

I. Basic concepts (14 hours)
II. Functions (32 hours)
III. Powers with natural number exponents (21 hours)
IV. Polynomials (41 hours)
V. Systems of equations (18 hours)
VI. Review; problem solving (10 hours)

Geometry, Pogorelov text (traditional Euclidean approach)
(2 hours a week; total: 68 hours)

I. Initial concepts of geometry (16 hours)
II. Congruence of triangles (21 hours)
III. The sum of the angles of a triangle (13 hours)
IV. Geometric constructions (15 hours)
V. Review; problem solving (3 hours)

Geometry, Kolmogorov text (geometric transformations approach)
(2 hours a week; total: 68 hours)

I. Initial concepts (23 hours)
II. Congruence of figures and displacements (19 hours)
III. Symmetries of figures (10 hours)
IV. The circle (8 hours)
V. Review; problem solving (8 hours)

GRADE 7

Algebra and Geometry (6 hours a week; total: 204 hours)
Algebra (3 hours a week during the first semester, 4 hours during the second; total: 119 hours)

I. Rational expressions (33 hours)
II. Inequalities (22 hours)
III. Approximations (15 hours)
IV. Rational and irrational numbers; square roots (24 hours)
V. Quadratic equations (17 hours)
VI. Review; problem solving (8 hours)

Geometry (3 hours a week in the first semester, 2 hours in the second; total: 85 hours)

I. Parallelism and parallel translation (17 hours)
II. Polygons (30 hours)
III. Vectors (20 hours)
IV. Similarity (13 hours)
V. Review; problem solving (5 hours)

GRADE 8

Algebra and Geometry (6 hours a week; total: 204 hours)
Algebra (4 hours a week; total: 136 hours)

I. The quadratic trinomial; systems of second-degree equations (26 hours)
II. Progressions (22 hours)
III. Powers with rational exponents (25 hours)
IV. Logarithms (40 hours)
V. Computer programming (8 hours)
VI. Review; problem solving (15 hours)

Geometry (2 hours a week; total: 68 hours)

I. The Pythagorean Theorem (8 hours)
II. Trigonometric functions (18 hours)
III. Metric relations in triangles (14 hours)
IV. Inscribed and circumscribed polygons (18 hours)
V. Review; problem solving (10 hours)

GRADE 9

Algebra and Elements of Calculus and Geometry
(5 hours a week; total: 170 hours)
Algebra and Elements of Calculus
(3 hours a week; total: 102 hours)

I. The derivative and its applications (54 hours)
II. Elements of trigonometry (39 hours)
III. Review; problem solving (9 hours)

Geometry (2 hours a week; total: 68 hours)

I. Parallelism in space (24 hours)
II. Spatial displacements; vectors (20 hours)
III. Perpendicularity in space (20 hours)
IV. Review; problem solving (8 hours)

GRADE 10

Algebra and Elements of Calculus and Geometry (5 hours a week in the first semester, 4 hours in the second; total: 153 hours)
Algebra and Elements of Calculus (3 hours a week in the first semester, 2 hours in the second; total: 85 hours)

I. Trigonometric equations and inequalities (18 hours)
II. Primitives and integrals (12 hours)
III. Exponential, logarithmic, and power functions (23 hours)
IV. Systems of equations and inequalities (12 hours)
V. Review; problem solving (20 hours)

Geometry (2 hours a week; total: 68 hours)

I. The coordinate method in space (10 hours)
II. Polyhedra (22 hours)
III. Solids of revolution (18 hours)
IV. Review; problem solving (18 hours)

The compulsory mathematics curriculum comprises 6 hours per week in grades 1 through 8 and 5 hours in grades 9 and 10 — a total of nearly 2000 class hours over 10 years. In this 10-year, period the Soviet program covers the equivalent of at least thirteen years of American schooling in arithmetic, algebra, and calculus, and does so much more thoroughly and effectively. It includes continuous and extensive treatment of plane and solid geometry, and culminates in a calculus course taught in grades 9 and 10. The magnitude of this achievement is reflected in the fact that in 1979 over 5 million graduates of Soviet secondary educational institutions had studied calculus for two years, while in the United States, at roughly the same time (1976), only 105,000 high school students were taking a one-year calculus course.

The entire curriculum in Soviet general education schools is compulsory, and the programs are essentially identical for the entire country. However, individual students can also develop their interests through special (elective) courses in mathematics, physics, and other subjects that have been offered since 1966. These elective courses (fakultativnye zanyatiya) meet 2 hours per week in grade 7, 4 hours per week in grade 8, and 6 hours per week in grades 9 and 10. Based on texts written by research scientists, they extend and enrich the compulsory school curriculum and periodically introduce new topics on an experimental basis. According to data from the 1973 school year, some 1,600,000 students in grades 7-10 participated in elective studies in mathematics and 750,000 students in elective physics courses.

The Kolmogorov school mathematics curriculum is a highly innovative program which has spurred development of similar programs in physics and chemistry. As in mathematics, these excellent programs were developed by renowned scientists, such as Academicians I.K. Kikoin and Ya.B. Zeldovich, and introduced only after years of experimentation. However, the new curricula came at the same time that compulsory secondary schooling was being enforced and the school population was exploding (between 1960 and 1975 enrollment in grades 9-10 increased more than four times).[8] The result was a severe burden on the Soviet educational system: students were overworked, parents were dissatisfied, and many teachers faced extreme hardships. The program exposed and aggravated the differences in cultural levels and educational standards between metropolitan and rural areas and between western and eastern (Asian) regions of the Soviet Union. The problems prompted a December 1977 resolution of the CPSU Central Committee ordering a review and revision of all school curricula, and of mathematics in particular.

It is indicative of the interest in school mathematics at all levels that this resolution initiated sharp public discussion and an open split in the USSR Academy of Sciences. While most of the Academy's mathematicians praised the inclusion of calculus in the compulsory program and did not question the range of the curriculum, some, including such internationally known mathematicians as L. Pontryagin, advocated a return to more traditional methods. The latter group launched a heated discussion in the pages of academic and educational journals, in the popular monthly Literaturnaya gazeta, and finally in a leading party organ, Kommunist. The revisions advocated have little to do with content and scope, instead focusing on approach and method. Essentially, they challenge Kolmogorov's set-theory approach, his geometry program based on geometric transformations, his "abstract and theoretical" definitions, and his heavy emphasis on logical rigor and precise language. Pontryagin and his group stress more intuitive and descriptive components and traditional methods and applications, and some schools are now replacing the geometric transformation courses with a more traditional approach.

Mathematics Education in Soviet Secondary Specialized Schools

Secondary vocational and technical education in the United States lacks prestige and appeal and has long been the poor relation of more academic studies. The Soviets, by contrast, have been particularly successful in the development of schools that train white-collar technicians and skilled workers -- the technicums and the technical-vocational schools, respectively.

The Technicums. The technicums offer a 3- to 4-year program for graduates of the 8-year school, and a 2- to 3-year program for graduates of the 10-year schools.

Corresponding to the German "technische Mittelschule," or to specialized community colleges in the United States, they are administered by the USSR's Ministry of Higher and Secondary Specialized Education and offer training programs in more than 500 specialties. They help promote universal secondary education, while producing white-collar technicians and specialists for all areas of the economy. Some of these institutions -- the pedagogical schools -- also train teachers for grades 1-3. In 1982, the secondary specialized system produced a million and a quarter graduates, with more than 60 percent having obtained training in engineering, agriculture, or management. In 1982-83, there were reported to be 4,418 technicums in operation in the Soviet Union, with a total enrollment of more than four and a half million students.9

The great demand for mathematics specialists with secondary technical training has inspired broader study of mathematics in the technicums, with special emphasis on applications. Soviet achievements in mathematics and mathematics education are now being applied with great fervor and commitment to the closely related areas of computer science, since the Soviets look upon automation of production and management as a key to overcoming some of the serious inefficiencies other aspects of their system impose on their economy.

In the technicum "Applied Mathematics" program, for example, students learn to formulate various practical problems in mathematical terms, create solution algorithms, and write computer programs for them. The course of instruction lasts 2 years and 10 months for graduates of the 8-year school and 1 year and 10 months for graduates of the 10-year school; admission is based on oral and written tests. The course requirements for the program are shown in the outline that follows.

Requirements for the Technicum "Applied Mathematics" Program

There are three groups of compulsory courses in this curriculum:

I. A general education group, the equivalent of all compulsory non-mathematics courses in grades 9-10 of the general education 10-year school
II. A general mathematics group. The usual curriculum of specialized secondary institutions provides for 350-400 hours of mathematics preparation (algebra, calculus, and geometry). In this

specialty, however, the mathematics program has been extended to 540 hours to include mathematical analysis, linear algebra and analytic geometry, mathematical logic, probability theory, and mathematics statistics.

III. A specialized group composed of two parts:
   A. Broader subject areas (algorithmic languages, programming and computer mathematics, mathematical programming, foundations of computer engineering and the organization of computer work, and operations research)
   B. Specialized areas (foundations of economics and the application of mathematical methods to problems in economics, the use of mathematical methods in automation and control systems, and mathematical techniques in natural science research)

In the "Computer Programming" specialty, students receive 668 hours of general mathematics in a course of instruction lasting 3-1/2 years for graduates of the 8-year school and 2-1/2 years for graduates of the 10-year school. They are taught numerical methods, programming and algorithmic languages, mathematical statistics, foundations of economics, and mathematical methods in planning. Graduates work in computer centers, laboratories, and construction bureaus, and in programming departments as assistants to engineers.

Another example of an applied mathematics curriculum is the "Information Processing in Automated Control Systems" specialty introduced in 1975. Here, the basic mathematics curriculum of 517 hours is supplemented by courses in computer mathematics, algorithmic languages and the foundations of programming, and mathematics software for automated control systems. Graduates are assigned to work in computation centers, laboratories, and departments in institutions which develop or use these systems.

Technical-Vocational Schools. The skilled workers required by industry are being trained in a system of over 7500 technical-vocational schools which enrolled 3,700,000 students in 1982-83.[10] The most modern and advanced of these are the Secondary Technical-Vocational Schools, introduced immediately after the 1966 resolution.[11] They provide 3 to 4 years of general education and technical training for graduates of the 8-year schools. A typical 3-year curriculum for future industrial workers, for example, includes 3000 hours of industrial and engineering training and some 2000 hours of general education. A trainee in the 4-year program in automated systems receives 1821 hours of general education courses, in addition to 4045 hours of specialized industrial training. The Soviets' own studies have shown that graduates of the secondary technical-vocational schools are more likely to learn new skills (50 percent within 2-3 years of starting to work), offer more efficiency and innovation in their work (4 times more than those without this training), increase their annual productivity 1.5 times as much as other workers, and advance twice as fast as other workers.

In spite of the cost of training in secondary technical-

vocational schools (estimated to be 5 to 6 times higher than for grades 9 and 10 in general education schools),[12] the Soviet government has increased the number of such schools from 71 in 1966 to some 4600 in 1982, with an enrollment of about 2,229,000 students.[13]

Other School Options. The term "secondary" in the formal designation of the secondary specialized schools (technicums) and the modern secondary technical-vocational schools can be misleading to American readers. These schools offering 3- to 4-year programs and designed mainly for graduates of the 8-year school actually represent a much higher level than that implied by the American usage of "secondary." An examination of curricula and text materials, especially in the technicums, indicates that in terms of scientific, technical, and mathematical content, the Soviet programs correspond to between 2 and 3 years at average U.S. technical institutes or colleges. And the number of white-collar technicians and skilled workers being trained in the Soviet Union is without equal elsewhere. In 1982, for example, Soviet technical-vocational schools turned out 2,516,000 skilled workers, of which 1,409,000 were graduates of the so-called secondary technical-vocational schools and technical schools.[14] The same year, Soviet technicums graduated 793,000 middle-level professionals in engineering, agriculture, and management.[15] In 1982, the Soviet Union also produced the following numbers of certified engineers with training equivalent to our masters in engineering programs: 310,700 in industry and construction; 42,800 in transport and communications; and 81,000 in agriculture (where emphasis is placed increasingly on advanced agricultural technology).[16]

Only 20 percent of the graduates of the general education 10-year school are admitted to institutions of higher learning (universities, polytechnical institutes, etc.), which require competitive entrance examinations. The remaining 80 percent may continue along one of the technical tracks for a shorter, specialized course of study in the technicums and secondary technical-vocational schools. In 1982, about one-third (983,000) of the graduates of the 10-year schools enrolled in 2- to 3-year programs in technicums.[17] The same year, about one-fourth (close to 800,000) of the 10-year-school graduates entered technical schools, which offer 1- or 2-year programs within the secondary technical-vocational school system.[18] Between 1970 and 1978, the number of technical schools grew from 364 to 1000, with a total enrollment of about one million students.

Overall, the educational expansion in the Soviet Union has placed heavy emphasis on science and technology. Some 3,300,000 graduates now enter the Soviet economy each year as skilled workers and middle-level technicians. Of these, over 2,200,000 have graduated from the technicums and secondary technical-vocational schools.[19] Their generally high educational and technical level promises to accommodate both present and future industrial and military manpower needs of a high-technology society.

This discussion has centered on secondary schooling, but it should also be noted that the Soviet educational mobilization of the past two decades has resulted in enrollments in institutions of higher learning more than doubling in the period 1960-1980, to some 5,300,000 students in 1982.20

Sharp discussions of the mathematics and science curricula and manpower training programs paved the way for the Supreme Soviet's adoption on 12 April 1984 of a further resolution, yet to be fully implemented, calling for continued comprehensive improvements in elementary and secondary schools and an ambitious expansion of technical-vocational training programs.21 Among the most important changes to be effected are the following:

1. Compulsory secondary education will be extended by one year, i.e., the 10-year secondary general education school will be replaced by an 11-year school; children will start school a year earlier, at age 6 rather than 7;

2. Far more emphasis will be placed on increasing the ranks of skilled workers, by greatly expanding the system of technical-vocational schools;

3. The content of existing school curricula and textbooks will be reworked, and improvements made in teaching methods, with an orientation toward practical applications;

4. Summer vacations will be shortened, and children involved in practical work;

5. Teacher salaries will be raised.

In addition to this 10 percent increase in the time allocated to compulsory general education, certain changes slated for the technical-vocational schools will have a direct and major effect on Soviet manpower needs in high-technology industry and the military. As earlier described, under the existing system, the common educational component for all Soviet youngsters is the 8-year school. On the basis of academic performance and examination results on completing grade 8, students are channeled into the technicums, the technical-vocational schools, or grades 9 and 10 of the general education schools.

An important feature of the recently adopted reforms is that students will be channeled into the various educational tracks after completing ninth, rather than eighth, grade. This will give skilled workers and technical personnel, who already have solid training, one more year of general education. The percentage of students channeled into technical-vocational schools will also change drastically, from the present 40 percent to 60 percent. This will be effected primarily by decreasing from 50 percent to 30 percent the number of students allowed to continue in grades 10 and 11 in the general education schools. The reforms call for large-scale construction of new secondary technical-vocational schools to accommodate the

tremendous increase in the number of students assigned to this track. The resolution calls for class size to be limited to 25-30 students.

The recently enacted educational reforms, to be fully implemented by 1990, should be viewed as changes designed to make the existing programs work more efficiently, to increase student achievement. They are designed to raise general educational standards even further while solidifying curricular gains introduced after 1966, and to direct the programs more towards applications. The increasing role of general education in Soviet manpower training programs is based on the Soviets' belief that the boundary between physical and mental work will disappear, as routine manual labor is taken over by robots. In summary, it is useful to view the Soviet educational reforms just enacted not as a departure from the existing multitrack system, but as a further expansion and improvement of the system, emphasizing the successes of previous manpower training programs.

The Role of Russian Research Mathematicians in Education

The Soviets' mathematics and science education in grades 1-10 has been developed to the point where the entire young population now receives two years of compulsory training in calculus. No nation outside the Communist bloc has ever attempted this. Although rather weak in some of the social sciences, the Soviets' compulsory general education curriculum is a remarkable achievement. More than just a product of the 1966 educational reforms, it is the cumulative result of a long-term government commitment, a sustained drive for outstanding education in service to the state, and a tradition of strong mathematics and science dating back to the eighteenth century. Prerevolutionary Russia's cultural and scientific development started with Peter the Great, who founded the Russian Academy of Sciences in 1724 and corresponded with Gottfried Leibniz. Of the 23 foreigners named to the Academy, 7 were among Europe's best mathematicians, including Nicolai and Daniel Bernoulli and Christian Goldbach. In 1727, the 20-year-old Leonard Euler, one of the greatest mathematical geniuses of all time, became a member of the Russian Academy of Sciences in Leningrad, where he spent 31 years.

In nineteenth-century Russia, some of the most prominent mathematicians were actively engaged in improving the teaching of mathematics at all levels. For example, N.I. Lobachevskii, P.L. Chebyshov, and A.N. Krylov, all world-renowned mathematicians, were among those who exercised great influence on education. The work of these and other scholars produced a strong educational system for the Russian elite. Although at least 75 percent of the population in old Russia was illiterate, the intelligentsia was very well-educated, and the Russian secondary schools (gymnasia) were comparable in every respect to the excellent schools of Germany and France.

The Soviets built on these traditions of educational excellence. In the 1920s, Academician S.G. Strumilin first emphasized the value of an educated population for the economic growth of the young Communist

state. Strumilin's research indicated a return of 5 rubles in the Soviet GNP for every ruble invested in education.22 Stalin's industrialization plans and his professed regard for mathematics inspired top Soviet research mathematicians to make major contributions to mathematics education.

Over the past fifty years, leading mathematicians have influenced school mathematics curricula, as well as program development, in the USSR's 200 pedagogical institutes (teacher-training colleges), at all levels. Furthermore, they have written the most innovative textbooks for secondary schools and pedagogical institutes.23

Moreover, Soviet research mathematicians have designed highly effective extracurricular programs to raise the general mathematical understanding of school students and their teachers, and to discover and develop mathematical talent from the earliest age. A secondary school mathematics circle was opened in 1934 at Leningrad University, and another a year later at Moscow University. The School Mathematics Circle at Moscow, founded by the young and later internationally famous mathematicians I.M. Gelfand, L.A. Lyusternik, and L.G. Shnirelman, became the model for a variety of superb extracurricular programs all over the Soviet Union.24

Now, on alternating Sundays, professors and docents of Moscow University deliver two-hour mathematics lectures on advanced topics and recent research for students in grades 7-8 and 9-10. Some of these lectures have been expanded and published in the series "Popular Lectures in Mathematics," which comprises over 60 volumes and has appeared in several editions in dozens of languages.

Individual sections of the Circle meet weekly under the supervision of graduate students of the Mechanics-Mathematics Department. The principal purpose of a section's activity is to stimulate interest in the field and independent, creative work; moreover, section discussions sometimes lead to new discoveries. Section activities of note are published in the "Library of the Mathematics Circle" to promote independent work by the reader.

The activities of the School Mathematics Circle culminate in a traditional mathematical olympiad for Moscow secondary school students, held annually since 1935.25 The olympiads are directed by a committee chaired each year by a different distinguished professor of mathematics. Winners are awarded certificates of merit and prizes; schools that have sent many participants, and the teachers of winning contestants, also receive certificates of merit. Many of today's most prominent Soviet research mathematicians -- I.N. Bernshtein, E.B. Dynkin, D.A. Kazhdan, G.A. Margulis, A. Suslin, and L.N. Vasershtein, to name a few -- are former winners of the olympiads in Moscow. Since 1960, All-Russian Mathematical Olympiads have been held for the students of 13 regions of the RSFSR and 9 other republics, and All-Union Mathematical Olympiads have been held since 1967.26 Following the example set in mathematics, physicists, chemists, astronomers, geographers, biologists, and linguists now also conduct olympiads for school students.

Soviet research mathematicians also contribute directly to special programs for the talented in mathematics. The following are particularly noteworthy:

- Schools for Computer Programmers. Established in 1959, these two-year schools (grades 9-10) offer much more intensive mathematics training than that provided in ordinary Soviet secondary school.[27]

- Mathematics (and Physics) Boarding Schools.[28] Established by research scientists for the most promising young talent, these schools, attached to universities or other institutions, offer a 2-year program devoting over 50 percent of the total curriculum time to mathematics and physics. The prototypes were founded in Moscow by Kolmogorov and at Novosibirsk University in 1963 by Academicians M.A. Lavrentev, S.L. Sobolev, and A.A. Lyapunov. Capable children from all over Siberia and the Far East are selected for admission to the Novosibirsk school on the basis of a three-stage olympiad. Such schools were subsequently established at the Universities of Leningrad, Kiev, and Tbilisi and in a number of other institutions across the Soviet Union. An excellent mathematics boarding school, for example, was founded and conducted by A.A. Stolyar, one of the foremost Soviet mathematics educators, at the Mogilev Pedagogical Institute.

- Evening Schools for Young Mathematicians.[29] These offer additional mathematics training to thousands of students in grades 8-10.

- The Mathematics Correspondence School. Established at Moscow University and directed by I.M. Gelfand, this program provides supplementary mathematics courses for capable secondary school students throughout the country. According to a 1974 report, over 3000 students were enrolled at the Moscow school, many thousands at its 27 branches, and 10,500 more at some 700 school mathematics clubs working under the direction of their mathematics teachers as so-called collective students of the Correspondence School. During the School's first ten years of existence over 20,000 students graduated from its 3-year program. Admission to the Moscow Mathematics Correspondence School is based on competitive entrance examinations (less than 20 percent of applicants are admitted), with strong preference given to children from rural areas; they represent 60 percent of those admitted, while 30 percent are from small towns, and only 10 percent from larger cities. Students from Moscow or Leningrad are not admitted to the School.

These and many other programs and schools for the talented give some idea of the magnitude of the Soviet investment in quality mathematics and science education. From all indications, millions of

Soviet secondary school students are currently receiving extensive supplementary training in mathematics far beyond anything offered their counterparts in the West. The experience of the USSR and the countries of Eastern Europe in providing programs for gifted students is extraordinary, and the translation and analysis of Soviet work concerning these special schools could provide American educators with a body of knowledge currently unavailable in this country.

To supplement school programs, Soviet mathematicians have also prepared an exceptional auxiliary literature for students and teachers. A major vehicle for fostering andstimulating secondary school students' interest in mathematics and physics, for example, is a highly original periodical called Quantum. The USSR Academy of Sciences and the USSR Academy of Pedagogical Sciences have jointly published this monthly journal, which has a circulation of about 180,000, since 1970.

For teachers, the Soviets publish Mathematics in the School, a bimonthly with a circulation of 390,810 (its American counterparts, The Mathematics Teacher and The Arithmetic Teacher, have a combined circulation of 84,000); Physics in the School, a bimonthly with a circulation of 176,670 (as opposed to the 7000 copies of its American counterpart, The Physics Teacher); and Chemistry in the School, with a circulation of 147,460.

Soviet scholars also publish several excellent and widely circulating journals in science and technology for both young people and the general public. Examples are the monthly Science and Life -- 164 pages, with a circulation of 3 million; Technology for Youth -- 68 pages, 1,700,000 copies per month; The Young Technician -- 84 pages, over 2 million copies per month; and Knowledge is Power -- 52 pages, with a circulation of 500,000.

SOVIET RESEARCH IN EDUCATIONAL PSYCHOLOGY

The depth of Soviet commitment to education is reflected in the work of the country's two most prestigious research insitutions. The USSR Academy of Sciences sets educational policy and determines curriculum design. More directly responsible for curriculum development, experimentation, and implementation is the USSR Academy of Pedagogical Sciences, the chief Soviet educational research center. The APS has 51 members, 83 corresponding members, and a staff of over 2000 scientists and experts.30 Among the major research institutes affiliated with the APS are the institutes for the study of the content and methods of instruction, general and educational psychology, vocational training, school equipment and instructional aids, and defectology, which is concerned with the special psychology and educational needs of the handicapped. The APS has 14 experimental schools and branches throughout the Soviet Union. This Academy has attracted a number of eminent scholars and promoted close cooperation between scientists and educators. No educational institution in the world remotely approaches it in size, range of operations, and quality of research.

Soviet research in educational psychology (particularly on the learning process) has benefited greatly from the USSR's official emphasis on education and service to the State. The permanent staff of the APS Institute of General and Educational Psychology includes over 500 senior research psychologists who, under the leadership of Galperin, Elkonin, and Davydov, are continuing the celebrated tradition of Vygotskii, Leontiev, and Luriya.

The focus of Soviet psychological research has been on the dynamics of mental activity and the learning process itself. The Soviets have investigated such areas as the development of mental operations, the formation of mathematical concepts and the related questions of generalization, abstraction, and concretization; analysis and synthesis; problem-solving; the relation between memory and thought; the development of logical reasoning; and the structure and indices of mathematical abilities. In a radical departure from their previous educational philosophy, the Soviets have over the past two decades devoted considerable attention to the individual and the development of independent thought and creativity. They have also emphasized programmed instruction, its psychological aspects, and its application for greater individualization in learning.

Using qualitative methods and working with small groups, the Soviets have been able to make penetrating analyses of children's mental processes. In this connection, they have designed special research-oriented classroom tasks and settings, so-called teaching experiments, and have emphasized longitudinal, developmental studies of learning.

The Soviets study child development under changing conditions of instruction. They assert that instruction broadens the potential for development, accelerates it, and influences not only the sequence of developmental stages in the child's thinking, but even the very nature of those changes. A case in point is provided by studies in the perception of three-dimensional space. In the United States, this ability had long been considered relatively static -- i.e., not much influenced by training -- until Soviet researchers (e.g., Ananiev, Chetverukhin, Lerner, Yakimanskaya) persuasively argued that it can be developed through instruction. Their seminal works were introduced to scholars in the United States through the series Soviet Studies in the Psychology of Learning and Teaching Mathematics. 31

The Soviets' tremendous efforts of the past forty years have resulted in a large body of outstanding research in the psychology of mathematics and science learning. This research, particularly in the area of the "teaching experiment," has been applied in reforming the content and methods of Soviet secondary school instruction, and has led to the development of a remarkable literature on the methodology of mathematics teaching.

To cite one example, a team headed by the well-known topologist V.G. Boltyanskii has produced excellent research on the theory,

construction, and application of various aids -- chiefly visual -- in elementary mathematics instruction.32 The premise is that much of the available equipment has been rendered obsolete by recent advances in psychology and pedagogy. Even such modern tools as filmstrips and videos have been regularly reevaluated in light of innovative curricula. This has led to the design of new equipment which is subjected to rigorous experimental testing in the classroom. In addition, Soviet research has facilitated advances in a number of other areas, from general manpower training and engineering psychology to special problems of man-machine systems and artificial intelligence.

The Soviets have also proven adept at assembling, generalizing, and exploiting foreign educational research in mathematics learning. In at least one notable case, their spadework has been a real boon to American research. In 1959, a French periodical published a study by Pieter Van Hiele entitled "La pensée de l'enfant et la géométrie" (Children's Thinking and Geometry), one of the most important breakthroughs in the psychology of learning and teaching geometry.33 Pieter and Dina Van Hiele-Geldof, together with their professor, the famous Dutch mathematician and educator Hans Freudenthal, introduced the concept of levels of mental development in geometry.34 This important paper went virtually unnoticed in both Western Europe and the United States. However, Russian monographs referring to the Van Hiele paper put me on the trail of significant research and experimentation done by the Soviets on the Van Hiele-Freudenthal theory. I was then able to report in a paper that the Russians had not only verified and refined the Van Hieles' work, but also gone on to adopt this theory as a foundation of their innovative curriculum and teaching methods in geometry. The paper ultimately stimulated a number of research projects in the United States, including programs at Brooklyn College, the University of Georgia, Michigan State University, and the University of Oregon.

For an idea of what educational research has meant for students in the Soviet classroom, let us note the sophisticated, efficiently-presented material in the USSR's standard science textbooks for grade 6. 35 The textbook Physics 6, edited by the world-renowned physicist I.K. Kikoin of the USSR Academy of Sciences, was published in 1978 in a printing of 3 million copies. The book begins with a general discussion of the tools, techniques, and applications of physical investigation. The initial chapters treat the structure of matter, and motion and forces. The chapter on hydrostatics and aerostatics begins with the basic principle of pressure transfer in liquids and gases. It systematically discusses more specific principles and laws and their applications in exploration and technology (ocean depths, aeronautics, etc.). The process of discovery is highlighted with interesting descriptions of the historic work of individuals such as Pascal, Torricelli, and Archimedes. This typically challenging and entertaining material, augmented by numerous illustrations, laboratory projects, exercises, and review problems, is being taught to all Soviet children in grade 6.

The sixth-grade biology course constitutes the first part of a two-year zoology sequence. The standard textbook[36] traces the lower phyla from the protozoa to the mollusks. Numerous color illustrations reinforce concise structural descriptions of various major classes within each phylum. The sixth-grade curriculum ends with a list of related summer projects.

Soviet sixth-graders divide their mathematics studies between algebra and geometry, which are taught in parallel sequences from grade 6 on. The algebra textbook[37] begins with basic concepts of expressions, statements with variables, and relations, and proceeds to linear and quadratic functions and their graphs, systems of linear equations, powers, and polynomials.

The sixth-grade geometry course is based on geometric transformations. Geometry is presented as a deductive system with definitions, axioms, theorems, and proofs. The text[38] is part of an excellent series edited by Kolmogorov. It begins with the basic concepts of geometry, concepts developed intuitively in grades 1-5 but now presented concisely and systematically. The 30 topics range from the concept of a figure to constructions involving circles, with major units allotted to congruence and displacements, symmetry and circles. Presentations are supplemented by review problems, hints, and answers.

One of the great strengths of the new Soviet programs is the elimination of the discontinuities that crop up in American curricula from course to course and from textbook to textbook. The Soviets' research in the psychology of learning has enabled their curriculum developers to avoid both duplication and gaps, and to construct a timetable for the optimal presentation of new concepts. Little, if anything, has been left to chance.

Here, for example, are some of the ways in which the sixth-grade mathematics curriculum is integrated with that of other disciplines and other levels. Skills learned in algebra, such as computing values of mathematical expressions and solving equations, are quickly and consciously put to use in physics and chemistry problems and laboratory work, e.g., in calculating distance, mass, pressure, heat quantity. The concept of a function and the ability to interpret graphs of functions are widely used in the physics course units on kinematics and on oscillations and waves. Direct and inverse proportionality are applied in physics topics such as hydraulic machinery, levers, the work done by simple machines, and Ohm's law, and in chemistry in such areas as thermal and mass relationships in chemical reactions. The physics unit on nonuniform linear motion utilizes what the algebra course teaches the student about linear functions.

The sixth-grade geometry course functions in tandem with the algebra course and applies many of the concepts of the latter, including relations, mappings, and equivalent transformations. In its initial stages, it draws on the fifth-grade geography course (orientation, measuring distance, representing direction and

distance, map-reading). It also serves as preparation and reinforcement for elements in subsequent physics and drafting courses. The physics curriculum, for example, applies concepts from geometry six in its study of circular motion, astronomy applies them to rotation and tangents, and drafting uses them in the construction of circles, tangents, and so on. These kinds of curricular interrelationships are not fortuitous, but the result of meticulous planning and experimentation.

The material in each of these sixth-grade textbooks is skillfully woven into the fabric of the overall secondary mathematics and science programs. Because of the scrupulous arrangement of the material, students are stimulated and challenged rather than discouraged or overburdened. By grade 10, they have attained both the competence and the confidence to deal with (1) a mathematics curriculum featuring a solid treatment of calculus and its applications; (2) a physics curriculum that includes introduction to the theory of relativity and nuclear physics; (3) a chemistry curriculum that studies topics in the structure of organic compounds, from relatively simple saturated hydrocarbons to the complexities of protein synthesis; and (4) a biology curriculum culminating in extended units on cellular biology, genetics, and ecology.

SOME COMPARISONS OF AMERICAN AND SOVIET EDUCATION

While the past eighteen years have brought great advances in the scope and quality of Soviet elementary and secondary mathematics and science education, studies have clarified the seriousness of our own educational crisis. A few striking comparisons will illustrate the enormity of our predicament.

As we have seen, practically every young person in the Soviet Union completes one of three versions of compulsory secondary schooling.[39] In the United States, on the other hand, only 73 percent graduate from high school. Even more telling than these general statistics are comparisons of programs and enrollments in specific subject areas.

- Of some 4 million American students who reach the age of 17 each year, at least 70 percent have been taught arithmetic for 9 years. Since such repetition takes no account of their developing abilities, our students emerge from this demoralizing experience without the inclination or ability to pursue secondary school algebra and geometry, the hard sciences, or technical-vocational training. In almost all other industrialized countries, children complete arithmetic in six years; in the USSR and the Soviet-bloc countries of Eastern Europe, arithmetic, in combination with intuitive geometry, is taught in the first five grades.

- Less than half of our students take any plane geometry.[40] Most of them never master it, because we attempt to teach it in a "packaged" one-year course, at an advanced level, to

students with inadequate preparation, even though empirical evidence and modern educational psychology tell us emphatically that we cannot. And since our high school students are not being taught solid geometry, they rarely have the workable perception of three-dimensional space that is essential to many areas of science, technical design, and engineering. In contrast, Soviet students study geometry continuously over a 10-year span: intuitive geometry in the first five years (at least one hour per week), semi-rigorous plane geometry in grades 6 through 8 (two hours per week), and solid geometry in grades 9 and 10 (two hours per week).

- American secondary school physics, another building block of science education and technical training, is in extremely poor condition. Less than one-sixth of our high school students take even a one-year course in this discipline,[41] while in the USSR, all secondary school students take a compulsory five-year sequence of physics courses. For some 16,000 U.S. school districts, the total number of full-time physics teachers (many of whom have never received specialized subject training in physics) is 8000 and decreasing. The total number of physics teachers in Soviet daytime general education schools alone is 119,000, [42] and the USSR trains another 8500 specialized teachers every year.[43]

- The pattern continues in other subjects. In chemistry, only one-third of our high school students take a one-year course,[44] while Soviet students are required to complete four years of chemistry, including a full year of organic chemistry. Soviet students also receive six years of compulsory training in biology, one year of astronomy, three years of mechanical drawing, and ten years of workshop and technical training. Class time spent on each of these courses is two or three hours per week.

- Our educational crisis is by no means limited to mathematics and the sciences. Only 16 percent of our students receive any exposure to geography as a separate subject, mostly in the form of a one-semester course. In the Soviet Union, on the other hand, all students take a five-year sequence of courses in the physical, economic, and political geography of the USSR and the world. While geography teachers have almost vanished from U.S. high schools, the total numer of geography teachers in Soviet general education schools is 94,000,[45] and 6000 specialized geography teachers are being trained every year.[46]

- All Soviet children are obliged to take six years of a foreign language, while not more than one-third of U.S. public high school graduates have studied any foreign language, and fewer than 4 percent have received more than two years of foreign language study.[47]

Soviet training programs for skilled workers and white-collar technicians are based on a general secondary education which includes algebra, geometry, calculus, physics, chemistry, geography, economics, international relations, history, and foreign languages. The vast majority of our own high school graduates have not studied physics, chemistry, geography, or a foreign language, and have had only a modicum of mathematics. They lack a solid foundation for further training; indeed, many cannot even apply basic mathematics and science to simple jobs. This situation not only hampers their functioning in an increasingly technical American society, but also diminishes America's overall position in the world and places a tremendous burden on the economy and society, on industry, which must invest huge sums even for narrow, short-term training, and on institutions of higher learning, which must provide costly remedial courses.

SOME ASPECTS OF THE PRESENT CRISIS IN AMERICAN SCHOOLS

The condition of American education is an extremely complex but sensitive issue that demands objective and thorough analysis and sober assesment. If we are to root out the sources of our current crisis, our perceptions must not be blurred by wishful thinking or any other predisposition to commend or criticize. With this in mind, let us take a brief look at three areas in which foreign efforts may suggest possible new approaches to the educational crisis in the United States.

Teachers

A country's educational system is a reflection of the entire society in all its complexity -- its history, culture, aspirations, and values. Ours is now producing alarmingly low numbers of competent teachers, particularly in mathematics and the sciences. Noncompetitive salaries and stressful working conditions may be largely to blame, but the root of the problem has been widespread public indifference to the quality and status of teachers in the United States. These circumstances cannot help but have a pernicious effect on all aspects of schooling.

Most of the students now entering schools of education -- that is, candidates for teaching positions -- posted low scores among high school students taking the Scholastic Aptitude Test. Furthermore, possibly as a holdover from the days of the one-room schoolhouse, American elementary school teachers, many of whom have no specialized training, are expected to teach mathematics. This is unfair to the teachers and often very damaging to the children.

What has helped to make the achievements of Soviet mathematics education possible is that, from the fourth grade on, the subject is taught by a specialized mathematics teacher whose training is equivalent to at least a master's degree program in mathematics in the United States. Even elementary school teachers (grades one

through three) receive extensive training in mathematics, the sciences, and educational psychology and teaching methodology based on advanced research. The same applies to the teaching of science and other subjects from the fourth grade on.

Educational Psychology and Curriculum Design

The steady decline of American school mathematics education has brought calls for new teacher training, new curricula and materials, and new "technological" instructional media. For reforms to have a lasting impact, however, they must be based on a genuine understanding of the nature and development of the conceptual and cognitive processes involved in learning mathematics.

We have already seen that Soviet research in educational psychology has been the cornerstone of educational reform. In the United States, on the other hand, a relative lack of applied psychological research has been partly to blame for poorly designed and uninspired mathematics curricula, impoverished programs with minimal standards, attrition in both student enrollments and the ranks of qualified teachers, lack of progress in applied programmed instruction (despite heavy investment and superior hardware), and declining interest and achievement in the hard sciences and engineering. To give one example, American students who take the one-year school geometry course generally have no prior knowledge of geometry and are working at Van Hiele's first psychological level of development. Yet they are expected to master material from the fourth development level.

As for high school science, the individual programs and textbooks for the American one-year physics and chemistry courses that resulted from the post-Sputnik national curriculum reforms are generally modern and comprehensive. Some of them have served a valuable function in training a new corps of outstanding scientists from among our academically superior students. Yet these one-year courses are, like our geometry course, written at the highest developmental level, with little regard for the students' learning processes. For the general population, these courses are simply too intensive and thus inappropriate. This is one of the main reasons why enrollments in physics and chemistry are so low.

In the Soviet compulsory five-year physics sequence, the student is first offered two years of intuitive, descriptive, and experimental physics two hours per week; then he or she is exposed to physics for three years (three, four, and five hours per week, respectively) at increasingly higher levels of sophistication and rigor. Soviet research in the psychology of learning and teaching mathematics and science has been aimed particularly at achieving this kind of level-by-level mastery. The one-year course in physics attempted in the United States should be replaced by a multiyear sequence (two to three class hours per week). The same applies to our one-year chemistry course.

Even the programs we have for our gifted students are painfully insufficient. Ideally, these students are our future leaders, but we do not equip them for such responsibility. This is a great waste of one of our most valuable resources.

Commitment

Some commentators have remarked on the failure of efforts to make lasting improvements in education in the period after Sputnik. These efforts have had only limited effect for two reasons above all: the reforms were geared to the more able student, and the impulse was not sustained. This is in sharp contrast to Soviet programs developed over a period of decades.

It takes twenty years to produce a qualified scientist or engineer, of which the first ten or twelve years of training are crucial. If our public schools cannot attract and hold students to the sciences, a generation of future scientists will be lost forever. Yet, as the standard measures of academic performance show, our educational system is producing fewer able students interested in these fields.

TOWARD A SOLUTION

As the preceding discussion of Soviet elementary and secondary education makes clear, the United States has both good reason and ample opportunity to capitalize on the Soviet example. The USSR's educational mobilization since 1966 has been an undertaking of mammoth proportions, the product of both historical efforts and a vast, ongoing commitment. As such, it unquestionably deserves our serious study. Unfortunately, we have not given adequate scrutiny to the educational system behind the "sudden" appearance of Sputnik, Soviet nuclear weapons, and other technological developments. Instead, we habitually assume that the Russians will always be technologically incompetent while our own schools will somehow find the leadership and resources to educate Americans for work and life in a high-technology world.

As early as 1979, I was reporting on Soviet-American comparisons in mathematics and science education, but the nation took nearly four years to start looking for a way out of the educational morass. In a historical context, of course, this is not a long time. But for today's rapidly changing world, too much time has already been wasted.

Fortunately, public awareness has, I believe, inspired a number of grassroots movements involving parents, teachers, and leaders of industry and government. We are now witnessing a period of increased hope and expectations. Various national committees and institutions have addressed the educational crisis in reports, such as A Nation at Risk: The Imperative for Educational Reform, by the National Commission on Excellence in Education. One of the most realistic and action-oriented reports, Educating Americans for the 21st Century,

was prepared by the National Science Board Commission on Precollege Education in Mathematics, Science, and Technology.[48]

One could cite many examples of society's constructive involvement in educational improvement; numerous recommendations from the reports are in fact now being implemented in schools throughout the country. In some school districts basic reading, writing, and mathematics test scores have increased several points; even Scholastic Aptitude Test scores are no longer decreasing.

While recent positive developments should be encouraged and expanded, we must not lose sight of the global picture. These are improvements in a relative sense, on a relative scale. In the international scheme of things, these changes are almost negligible. We must measure the state of U.S. education against that of other nations, in particular our economic competitors and military adversaries. This analysis has used international comparisons to demonstrate the magnitude of our problem. The same studies suggest methods and approaches that will prove useful in the American context.

RECOMMENDATIONS

Comparative studies and other evidence point to a formidable challenge we have to face to maintain America's present position and secure our future as a leader in science and technology. In order to maintain our country's scientific and technological abilities and overall economic vitality, we must raise the nation's general educational achievement by three to four years — to the level already achieved by secondary school graduates not only in the Soviet Union and Eastern Europe but also in Japan, South Korea, and Taiwan.

Resolving our educational crisis, I believe, will be an undertaking of unprecedented magnitude. It is evident that the policies and measures instituted to date do not approach the kind of changes needed. One answer is a federally sponsored national mobilization for education and a coordinated mobilization in each of the states.

A prerequisite, of course, is basic literacy (since the 1950s, the United States has dropped from 18th to 49th in a literacy ranking of the 159 members of the United Nations). Innovative courses, sophisticated textbooks, and superior professional guidance will all go for nought if students are unable to read or write. It is therefore essential that we upgrade the high school graduation requirements for English to four meaningful years. To help create a global perspective and provide the background for an understanding of international relations and foreign cultures, geography (two years), foreign language (two years), world history, and economics should all be included among basic requirements. It might be noted that teachers of English in the Soviet Union outnumber students of Russian in this country.

In spite of the USSR's tremendous achievements, I do not recommend that we adopt the educational goals or practices of the Soviets' dictatorial regime. Nor should we attempt to imitate the highly successful centralized system used in Japan. We have a decentralized system that is in many ways a model of freedom and democracy. We must preserve that system and make it more efficient.

In addition to substantial improvements in the recruitment, training, and overall situation of teachers, the highest priorities are major curricular reforms and long-term structural changes. Here are only a few recommendations derived from my experience, research, and observations:

- Concentrate more on education and training in the first eight years of schooling, and establish requirements for graduation from primary school. Unfortunately, too much is left to high schools, which in four years at best cannot achieve what schools in other nations do beginning in the earliest grades.

- Greatly expand the system of preschool education. Appropriate teacher training programs should be introduced for this level. Children from the age of three or four can become acquainted in an organized way with the concept of numbers, some basic ideas of geometry, and underlying patterns and relationships in mathematics and science.

- Develop a completely new mathematics program for all children, covering all of arithmetic in the first six years of school. Intuitive geometry should be an integral part of the new program from the first grade on.

- Allow only specialized teachers to teach mathematics and science courses from grade five on.

- Establish ongoing training programs for primary school teachers, especially those who teach arithmetic in grades 1-4. Inservice and preservice programs should be devoted mainly to teaching content, particularly the fundamental concepts of mathematics and science.

- Replace the one-year geometry course with a three-year sequence in plane and solid geometry (three hours per week).

- Make optimal use of calculators and microcomputers in the new mathematics program. The ready availability of these tools in the United States should be exploited to greatest advantage at all educational levels, starting in the primary grades. In high school, offer separate courses in computer science and statistics and probability, in addition to the existing courses in advanced algebra and calculus.

- Replace the one-year course in physics with a three-year sequence (three class hours per week) developed according to the latest level-by-level theories of learning. Similarly,

replace the one-year chemistry course with a two-year sequence.

- Introduce a new sequence of courses on "Technology and Engineering" (two to three hours a week for up to four semesters), begun in grade nine and offered to all students in all school systems. Whenever possible, the curriculum should combine theoretical and practical studies, ideally using modern, well-equipped shops and laboratories at nearby industrial or commercial enterprises.

- Organize extracurricular programs to develop students' interest in mathematics, science, and technology. These programs should be designed to excite students and ensure the participation of the best teachers and scholars from all school levels, as well as scientists from industry. The programs should be preceded, and then accompanied, by specially prepared literature that makes use of all the available media -- books, carefully designed and widely distributed periodicals, and video presentations on tape and disc. The Public Broadcasting System, museums, and other public educational institutions should be encouraged to provide integrated programs and services.

- Organize new programs and expand existing ones (such as summer programs) for the discovery and training of mathematically talented children from the earliest possible age.

- Expand our research community in the psychology of mathematics and science instruction. If we are to accomplish the curricular reforms outlined above and stimulate and coordinate research efforts, we must create a national R&D center for mathematics learning (not combined with science). The new center should be established at an institution of higher learning, or a consortium of institutions, selected on the basis of quality and the greatest promise of active participation by a range of outstanding mathematics educators, research mathematicians, and specialists in the psychology of learning and teaching mathematics. Similar separate R&D centers for physics, chemistry, and other disciplines should also be established.

- Institute a program for the development of a literature on teaching methodology for all subjects at all levels of the primary and the secondary school system. This literature should address both content of instruction and teaching methods. It should make use of the classroom experience of outstanding teachers, modern research in the psychology of learning and teaching, and the theory and use of instructional materials, including audiovisual aids, calculators, and microcomputers. A comprehensive literature of this kind, developed over a long period of time and continually revised and improved, is being used in all Communist countries to

assist inservice and preservice teachers. Such a literature is completely lacking in the United States.

- Conduct research on the theory, design, and application of various aids -- principally visual -- in elementary school mathematics instruction. The premise is that much of the available equipment, both older and more recent, has been rendered obsolete by advances in mathematics and psychology. Even such modern tools as filmstrips and slides must be reevaluated in light of new educational goals and conditions. Newly designed equipment has to be subjected to rigorous experimental testing in schools.

- Seek new ways to come to grips with the tremendous shortage of trained mathematics and science teachers. Although technology is no substitute for capable teachers, the future will undoubtedly bring greater reliance on microcomputers, video, and other equipment for computer-assisted instruction. Further, we must make more extensive and intelligent use of our abundant instructional resources by committing ourselves to continuous research and experimentation in the psychology of learning and teaching.

- Encourage institutions of higher learning and their colleges of education to reevaluate their activities and assume new responsibilities with regard to high-quality teacher training programs and the establishment of close working ties with the elementary and secondary schools in their area.

- Organize or expand continuing education programs for adults who need additional training. We must enable individuals to understand and appreciate new developments in science and technology and offer them an opportunity to study in depth. Schools from secondary level up should be used, as well as museums and popular media.

- Accompany these comprehensive organizational and curricular reforms with research and development programs giving special attention to integration of the sciences, particularly in their relation to mathematics. This research should be applied to the interrelationships of subjects and the establishment of a logical order of presentation in school curricula at each level.

- Encourage more active educational involvement by research scientists. In contrast to the tremendous contributions of Soviet scientists and scholars to their nation's education, our own scientific community, with a handful of notable exceptions, has demonstrated little commitment to precollege science and mathematics education over the past fifteen years. This situation must not continue. For the sake of the survival of the scientific community and the nation, our top scientific research institutions, professional associations, and the National Academy of Sciences must help to recast

American secondary education.

- Create permanent national curriculum centers and a national review board in science and technology. These bodies should include the nation's top scientists and engineers with educational expertise, researchers, outstanding teachers, educators, and psychologists. They would supervise the development of new curricula and review the implementation of programs and text materials.

CONCLUSION

As a national concern, education is as vital as defense and foreign policy, and, like them, it requires national leadership. This will require a sustained effort by all segments of our society, private and public investment, and, above all, imaginative and engaged leadership at all levels of government.

We must acknowledge that an educated population and a well-trained work force are essential to the recovery of our country's dynamic spirit and economic strength. Then we must go beyond mere recognition of the problem and mount a serious effort, a genuine national mobilization for education to bring us to the worthy goal proposed by the National Science Foundation, namely, "providing the Nation's youth with a level of education in mathematics, science, and technology that reflects the needs of the Nation and is the highest quality attained anywhere in the world." This will require creativity, energy, wisdom, and patience. From leaders of industry to concerned parents, the American people are looking for national leadership and a decisive program, for they are ready to apply their optimistic spirit and practical ingenuity to an educational revival. To give up, to procrastinate, or to plan only for the short term would be to mortgage our freedom and our future.

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6. Lessons from Five Countries

The preceding chapters make the conclusion inescapable: Japan, West Germany, East Germany, China, and the Soviet Union each have an explicit, unambiguous, and strong national commitment to science education. Each has a policy calling for every student to receive a thorough grounding in mathematics and the sciences. Each is strenuously engaged in improving its ability to implement that policy. And each believes that its future -- its economy, its security, its status in the world, its attractiveness as a human society — will be strongly influenced by its success in doing so.

As a nation, the United States displays no comparable commitment. That it is essential to make such a commitment is, I believe, the most important lesson to be learned from this study. But there are other basic differences between U.S. policies and practices and those common to these other countries. To the degree that these countries -- so different from each other in history, resources, economic development, political philosophy, and geography -- are doing similar things in science education, we should pay attention. This is especially so when it appears that we alone are out of step. The point is not that the United States should simply get in step, but that it may have something to learn from them. To act as though our ways in these matters are always and necessarily superior is arrogant and, given the global stakes, risky; to claim that we cannot do things differently — because of the cost or the "politics" — is defeatist, belies our history of educational and social innovation, and underestimates our resources.

Conclusions on what China, Japan, the Germanies, and the Soviet Union have in common in science education that we in the United States should pay careful attention to are presented in Part I of this chapter. Part II consists of recommendations for action based on those conclusions.

I. LESSONS

In the specific details of science and mathematics education in the countries under review, diversity prevails. They vary among themselves on such matters as the scope and sequence of topics, the

organization of instruction, the time devoted to science instruction, the creation and distribution of teaching materials, single or multiple student "tracks," kinds of facilities, and much more. But there also appear to be remarkable similarities. These are structural, having to do with design and function rather than day-to-day operation, although the two — structure and operation — yield competently educated students only if each effectively supports the other.

In contrast to the United States, China, Japan, East Germany, West Germany, and the Soviet Union have science education systems characterized by the following common features:

1. An unmistakable commitment to the achievement nationwide of science and technology literacy as well as the training of students for careers in science and technology.

2. A high priority for science and mathematics instruction in all schools at all levels.

3. Direct national interest in the preparation of competent teachers of science and mathematics for the elementary and secondary grades, with quality and content of training not something to be left to local whims or to be neglected by institutions of higher education.

4. Provisions for increasing the effectiveness of teaching on a continuing basis.

5. Processes involving both teachers and scientists for ongoing curriculum development in science and mathematics.

6. Examinations and external monitoring as part of the quality control processes in science education.

National Commitment

Just what is it that constitutes the "national commitment" of Japan, say, or of the others, to science education? What do they have that we do not? The answer, I believe, is threefold: national leadership, national planning, and national policymaking.

In these countries, the top political and educational leaders garner and sustain public support for scientific and technological literacy. Using methods appropriate to their individual political circumstances, these leaders help their educational systems respond cogently and forcefully to the growing awareness, worldwide, that a nation's security and economic health increasingly depend on all youngsters getting a good education in mathematics and the sciences.

Such leadership is a precondition for the kind of careful planning that leads to attainable goals and workable policies. In

each of the nations studied here, continuous planning is used in deciding how best to achieve nationwide science literacy. It is instructive that in this process even those countries with the most centralized governments are careful to seek wide participation, local and regional as well as national, political as well as educational. To be sure, this has not always resulted in total harmony or perfect solutions, but out of it has come the realization that there is in fact a national policy with regard to science education as well as a working agreement on what needs to be done, who will be responsible for doing it, and how it will be financed.

Compare that to the situation in the United States. Our planning is sporadic and haphazard. In spite of a plethora of recent reports[1], we have not agreed, as a nation, upon clear science education goals nor on how the division of responsibility and cost is to be divided among the various jurisdictions and institutions that comprise our political, educational, and scientific fabric. This is not surprising since national leadership has long been absent: not since Dwight Eisenhower has an American president launched major new initiatives in science and mathematics education.

School Priority for Science and Mathematics

National educational goals need to be reflected in school priorities if they are ever to be reached. Achieving nationwide science literacy is a declared goal in China, Japan, the two Germanies, and the USSR; and, appropriately, science and mathematics enjoy a priority second only to command of the native language in the schools of these five countries.

The high priority accorded science education is expressed most unmistakably in terms of course requirements. All students are required to study science and mathematics every year; these subjects are held to be too important, too basic, to be left to student option. In Japan, a country without a track system, all students take exactly the same courses, all are expected to succeed, and some 90 percent do. Where students are sorted according to vocational futures, as in West Germany, the treatment of science and math may vary among tracks, but in every case those subjects are still required of all students.

It is worth noting that by ranking science and mathematics with the native language, the schools are in effect putting students and parents on notice that these subjects are especially important and are learnable by all. This message goes to the heart of all calls for universal science literacy, just as the counter notion -- science and math are too difficult to be learned by any save the very brightest students -- undermines any serious effort to achieve it.

The other measure of priority in the schools is time. It is a valuable and limited commodity, and how much time is given to a

subject is a direct measure of its curricular status. In these five countries, science and mathematics are not only required of all students year after year, they are also allotted a sizable fraction of the time available for instruction in each year. On average the schools in these countries invest about 20 percent of class time in science and math, approximately the same amount given to language.

By either measure -- substantive requirements or time allotted -- schools in the United States do not give a high priority to science and mathematics. Science requirements are everywhere limited in number; they vary widely from region to region, state to state, school district to school district; and what few requirements there are are very general. Many states require one year of "science" for high school graduation, but some require none. Some local school districts require more than the state minimum, but many do not. And the same applies to mathematics.

To be sure, in the American educational system students can elect to take more science and mathematics than is required for graduation. And college-bound students often do, either because they are interested in a scientific career or because it may increase their chances for college admission. On the other hand, many students deliberately elect not to take "extra" science courses (especially physics and advanced math) for fear of lowering their grade point average and, consequently, making it more difficult for them to get into the college of their choice.[2]

So many different standards prevail throughout the United States that it is not possible to say how much science and mathematics all students get in this country, nor can we give a description of the usual course content. What we do know is this:

1. During the elementary school years science instruction ranges from almost none to very little. Mathematics fares better, but unlike other countries where higher order math is introduced by the fourth grade, here most of the time is devoted to simple arithmetic.

2. During the middle grades -- 7, 8, and 9 -- students typically take one or two years of general science and often a year of earth science, but less is not uncommon. Math is required each year, but for the general student it is just more arithmetic.

3. In high school students can often get by with as little as one year each of science and math, although in most schools they can elect to take both subjects every year.

It is clear that schools in America have not put science literacy for the general student at or even near the top of their list of priorities. The contrast with schools described in earlier chapters is striking.

Teacher Training

Every country faces the problem of attracting outstanding young people into science teaching careers and insuring that they receive the best possible preparation for that profession. But insuring an adequate supply of competent science and math teachers is regarded as a matter of national consequence and interest in all five countries examined here. The actions these governments have taken include actively recruiting talented young people into science teaching careers, establishing high standards for entry into teacher education institutions, providing first-rate teacher preparation programs in those institutions, and instituting strong credential requirements.

These actions reinforce respect for the teaching profession, and teaching science in the schools of these countries is not generally looked down upon by either the public or the research community. Selective entry standards and substantive course requirements mean that not everyone can get into teacher training programs, and those students who are admitted find their course of study carefully designed and demanding. Students are expected to emerge knowing their science subject well, but with a focus on the basic logic, principles, and relationships which need to be understood by those who will teach the subject in the schools. Such training is necessarily distinct from that given future researchers. When university training is complete, student teachers are ready to begin as novice teachers under supervision, having already developed a strong sense of professionalism and commitment. Graduates must also pass rigorous examinations in their science field in order to be licensed to teach. In all of this the universities do not treat the training of teachers of science and mathematics any less thoughtfully or responsibly than that of research scientists and mathematicians.

In the United States almost none of these conditions prevail. Science teaching is a low-status career, and young people are not readily attracted to it. There is no national or local tradition of active recruiting of students into teaching; teacher training institutions take whom they can get; and many prestigious universities have been sloughing off responsibility by getting out of the business of science teacher preparation altogether. Collectively, our top science universities produce very few science teachers, and many of "the best" produce none.

Those institutions that do train science and mathematics teachers for the schools are not held to any national standards, or even expectations, of excellence or productivity. State governments make little or no effort to insure a sufficient supply of science and math teachers and often remove incentives by making it legal and convenient to assign persons without science or math credentials to teach those subjects. By international standards, the credential requirements of the individual states are weak. Requirements, such as they are, are typically expressed in terms of general categories of courses, without regard to the quality or appropriateness of the material actually covered in a particular college or university class. National accreditation has focused on only the schools and

colleges of education and has not worked3. The accrediting agencies lack authority and sanctions over either education faculties or the science and mathematics faculties who are no less responsible for our failures of quantity and quality of teachers of their disciplines. As previous chapters make clear, other nations have concluded that they must have a continuing supply of skilled professionals to teach key subjects and have instituted plans of action to see that their needs are fully met. I see neither plans nor actions in the United States.

Effectiveness of Teaching

Schools everywhere are heavily burdened. They are charged with inculcating "the basics," teaching intellectual skills appropriate to the times, teaching a substantial fraction of the world's large and rapidly expanding body of knowledge, and reinforcing societal values. In virtually every country they are also expected to perform a variety of social services. This menu puts a premium on effectiveness.

The countries studied here have taken measures to make instruction in science and mathematics as effective as possible, given the resources at hand. These measures have to do with the amount of time to be spent on learning, structure of the curriculum, tasks teachers must perform, and above all, continuing teacher education. All are structural. The contrast with the United States is stark, as the following brief comparisons attest:

1. To learn a substantial amount of science, students must devote the necessary time to the task. Factoring in days of instruction per year (about 180 in the United States, 210 to 220 in the other five countries), actual attendance patterns, length of school day and week, fraction of total school time allotted to science, and amount of homework assigned, it appears that American students spend one-half to one-third as much time learning science as their counterparts in the USSR and the other four countries. The picture is only slightly better in mathematics.

2. This time difference might not matter if we were making proportionately better use of the time available for science teaching. Unfortunately, our curriculum structure is a model of inefficiency. Our helter-skelter science curriculum is unarticulated from grade level to grade level and encompasses no planned sequence that can be counted on. We talk a lot about "K-12" science, but we rarely have it, even in individual school districts or states. Nor do we have spiral curriculum designs, which permit controlled redundancy and matching of concept development to student maturation.

3. Effectiveness of curriculum and of instructional time depends mostly on the capability of the teacher. Our

comparison countries rely on science specialists -- persons who have had advanced training in teaching science to young children -- beginning in the very early grades. We still depend largely on "generalist" teachers in the elementary schools, most of whom know only a tiny amount of science themselves. In secondary schools we commonly treat teachers as though they were not specialists, assigning those trained to teach one science -- say, biology or mathematics -- to teach another -- say, physics -- or even worse, requiring teachers of nonscience subjects, such as history or home economics, to teach science.

4. Even well-trained teachers will not remain effective if they do not stay up to date in subject matter and knowledge of techniques and materials. Each of the five nations recognizes this by providing a variety of opportunities for continuing self-improvement and by the firm -- and monitored -- expectation that all teachers will, as a measure of their professionalism, participate. For science and mathematics teachers, the focus of most of these continuing education activities is the school curriculum in those subjects. In the United States, opportunities do exist, but they are scattered, expensive, unsystematic, and often unrelated to the curriculum in a particular school. Teachers are given little time during the school day or year for study, and they are not expected, and usually cannot afford, to use their summers for that purpose. Obsolescence is scarcely the road to effective teaching.

Curriculum Development

All of the five nations reported on in this volume regard the content of compulsory education to be a matter of national interest. Their central governments believe they have a right and an obligation to be involved in shaping the curriculum in the required subjects. The form and degree of involvement vary, as do the actual mechanisms used, but these nations operate from similar premises about the process and purpose of curriculum development. In the case of science and mathematics, these premises include the following:

1. The selection of content, including its scope and context, should make sense in terms of national goals. If, for example, the goal is nationwide science literacy, then the science curriculum should be designed expressly to serve the future needs of all students, not just the most talented.

2. Science teachers must participate in curriculum development, for only they possess the actual classroom experience needed to judge what content can be taught by most teachers and learned by most students.

3. Practicing scientists must also be involved in selecting and organizing the material to be taught since they have a deeper grasp than teachers of the nature of contemporary science, its content, structure, methods, and values.

4. Curriculum reform must be continuous. There is no perfect curriculum, but an existing one can get progressively better if it undergoes periodic revision based on experience and new insights. Furthermore, only evolutionary reforms can accommodate the continuously changing worlds of science, students, teachers, and circumstances. Spasmodic reform efforts which require sudden changes are usually ineffective. On-again, off-again changes keep the system off balance, and efforts launched in times of extreme dissatisfaction frequently call for revolutionary changes that are hard to institutionalize.

Especially with regard to the first and last of these premises, we stand apart from the other countries. Except for the efforts following the Sputnik episode, our national government has not engaged in curriculum development, nor has there been a mandate for it to do so. Local school districts and most states, for their part, lack the resources to conduct sophisticated, broadly useful and nationally significant curriculum projects or to disseminate them. Thus, national goals and needs have not generally been taken into account in any systematic way in deciding on the content of science and mathematics courses.

Practically speaking, our curriculum is established mostly by the process of textbook selection. But science and mathematics textbooks themselves are rarely developed systematically. They are seldom produced by teams of scientists and teachers working together over time in the specific context of national needs and goals. Many texts are written by small groups of people working on their own time, under the loose supervision of a publisher's in-house editor. Content is heavily influenced by the selection committees of three or four large "textbook adoption states," since no publisher wants to be excluded from so large and concentrated a sales base. The texts are not for these reasons necessarily poor, but claims that they are the end product of a national curriculum development process are not supportable.

There is one notable exception: the curriculum development projects of the 1960s. Then a national process was initiated and refined to address a national need. With federal stimulation and resources, teams of scientists and teachers all over the country turned their attention to the reform of science and mathematics education as a necessary step in restoring the nation's scientific and technological leadership. That was our first effort to rationalize science education from top to bottom and to invent new approaches that would be more effective, motivationally and

intellectually, than those that had existed unchanged for decades.[4]

Some of the new curricula were outstanding, some not, but the development process was working. Then the effort, never viewed as a continuing process, came to an abrupt halt.[5] Because it had been justified as a response to a particular national crisis, curriculum development in science and mathematics could be discontinued once the crisis was believed to be safely past. Now, a quarter of a century later, another crisis could lead to another round of furious effort. Both logic and the example of other countries should show us that we would be much better served by a policy of on-going curriculum improvement than by alternating long periods of neglect with short periods of frenzied action.

Quality Control

Finally, we come to the most sensitive matter of all: How can quality be assured nationally? What can a nation do to see that its science and mathematics teachers are competent, no matter where they may have been trained? What can it do to motivate students to learn science and mathematics well? China, Japan, East and West Germany, and the Soviet Union give essentially the same answer: set national standards and then monitor performance against them.

Upon completion of their studies in these countries, prospective teachers must pass an examination to become certified. A transcript of courses taken is not sufficient. The tests normally cover both subject matter and pedogogical knowledge, and they are designed to national standards and administered, not by the institutions themselves, but by an agency of the central government, or in some instances by a state agency. This "third party" measure of readiness to teach science or mathematics serves as a minimum quality filter between the teacher training institutions and the schools, and over time, it provides a measure of a training institution's performance as well.

The use of external examinations to sort and monitor is not confined to teacher education graduates. Students in these countries encounter external exams periodically as they move through all levels of education. In spite of the well-known limitations of tests and their potential for abuse, they are used in these countries as one way of showing students what they are expected to learn and teachers what they are supposed to teach, for identifying levels of attainment somewhat more objectively than by course grades, and for monitoring the educational system as a whole.

An enormous amount of testing goes on in the United States, but none of it shows students or teachers or institutions how well they are doing, by national standards, in science and mathematics.[6] The Scholastic Aptitude Test purports to measure general academic ability, not knowledge of any particular field, and it is not taken by all students. Similar considerations apply to the Graduate Record Examination. The National Assessment of Educational Progress

makes estimates of student learning in science and mathematics but is aggregated by region and is of no direct value to the individual student, school, or state. The College Board offers examinations in the various academic fields, but they are optional and only taken by a small number of self-selected students.

Some professions — law, medicine, and accounting, for example -- depend upon examinations to select those who have mastered at least the basic knowledge of the field; no such gatekeeping system exists in science and mathematics teaching. The National Teacher Examination is not widely used for licensing purposes, and in any case does not cover individual science fields in depth. National professional associations of scientists, mathematicians, and science and mathematics teachers have not attempted to design and make available to schools and states valid tests of either science and mathematics or of competency in science and mathematics teaching. The net result is that, unlike its competitors, the United States has no system of overall quality control.

II. RECOMMENDATIONS

If these conclusions are on target, then reform of science education in the United States means that we must achieve a national commitment to better science and mathematics for all students, raise the priority of these subjects in the schools, improve the quality of science and math teachers, institute ongoing curriculum development, and establish quality controls. To get from these conclusions to the recommendations that follow, however, requires an examination of several intervening assumptions. Briefly, these are:

- We begin where we are. This is with a highly decentralized system that is inadequately staffed and equipped to teach science and mathematics. It is, furthermore, a system without a shared vision of where it is going or how best to get there, one whose practitioners are held in low esteem by the nation.

- Political realities, as well as substantive ones, need to be taken into account. Successful school reform in a noncentralized system in which authority and influence are widely distributed must necessarily involve all groups that have a stake: parents; school teachers and administrators; scientists and other scholars; universities; employers; and business, labor, and professional associations.

- A decentralized system is merely a fragmented system unless there is a nationwide commitment to national goals. Thus of all of the lessons encountered in this volume, the one calling for establishing science education as a national priority is foremost.

In our nation, a commitment to any goal -- be it full employment, clean air, scientific and technological preeminence, or

excellence in education -- has to grow, take shape gradually, and draw content and energy from diverse sources. There is no way to get it instantly by fiat. A blizzard of reports or a crescendo of speeches -- ringing or otherwise -- is as much a reflection of a developing public concern as it is a part of the process of arousing that concern. The process is not tidy, let alone systematic. But when the resonances are right, action begins to match rhetoric in enough different places to make it apparent that in our often confused, bottom-up, top-down, meet-in-the-middle system we have indeed managed to reach what can be called national commitment.

A commitment to the goal of significantly improving our science education system does not necessarily imply, however, consensus on how best to reach that goal. Our acceptance of educational decentralization as a prior and superior value carries with it the willingness, at least in theory, to accept some measure of inefficiency; thus total agreement is not of the essence. What is required is a commitment that is deep enough and sustained long enough for diverse programs of action to achieve a critical mass of effort and to produce enough positive results to sustain that commitment and refresh it.

The question then arises, What can we do to promote and sustain such a national commitment? The following nine recommendations are not intended to be comprehensive; rather, they are meant to be provocative, to generate discussion and debate, and to expose fundamental issues. Each was selected because it has many ramifications both philosophical and practical, and therefore connects to the fabric of education at many points. None of the set is powerful enough to stand alone, for there are no panaceas, no simple solutions, not these or any others. Collectively, the recommendations strongly favor persistent, long-lasting mechanisms over short-term measures to deal with the immediate crisis. Adoption of these measures would change our ways of doing things in science education, indeed, in education in general, but that does not mean that they are out of reach. It is a question, at bottom, of whether we wish to reconstruct the system to function efficiently for the forseeable future or only to patch it up and, in a few years, find ourselves in even more serious difficulties than we face today.

The nine recommendations that follow are divided into three groups. The first set deals with the school, the second with teacher preparation, the last with the federal government. While that order is roughly from local to state to national, the overlap is large, and concurrence -- and sometimes collaboration -- among jurisdictions is essential and implicit.

Schools

Responsibility for public education in the United States is broadly shared, but in ways that defy ordinary logic and that are difficult to specify except in broad outline. Nevertheless, the

fundamental fact is that the individual school is still the place where we expect systematic and deliberate education to occur. The public, speaking through a jumble of boards, agencies and legislatures, sets policies and provides resources; but what finally happens, for better or worse, does so in the schools. Thus we must ask what can be done at the school level to make possible better science and mathematics education.

Recommendation 1. Each individual school, as a school, should be held publicly accountable for the quality of science and mathematics learning of its students.

Most of the current public discussion about improving science education has focused on individual teachers, or at the other extreme, on huge systems. The thrust of this recommendation is that the individual school is the appropriate unit of reform. Having one or two good teachers in a school does not do much for students who draw less capable ones. Good teachers are ineffective if the curriculum is not right for the students, or if teachers are not supported by the principal and counselors, or if the school's goals are flaccid and undemanding, or if community attitudes toward the school are negative. The school as a discrete entity staffed by a team should be held responsible for its performance. Several aspects of the team concept need to be explored.

First, it is easier to assess the performance of a self-contained organization, a team, than that of individuals, especially in education where the number of variables is so large. Ambitious but attainable goals can be arrived at by negotiation between teachers and their principal, with significant community and parent input, and then between school and governing board. Performance over a predetermined period of time, perhaps three years, would then become the measure of a school's success in reaching those goals. Such goals in science would, of course, have to express what was expected of all students as a consequence of the total school science experience, taking full account of the nature of the student population in that school.

Second, goals -- a specified fraction of students taking a particular number of science and mathematics courses, minimum scores of students on particular content examinations, and so forth -- should be publicly announced and the principal required to give a public accounting at specified intervals of progress made. Rewards for outstanding performance should be given to the school and be shared by all faculty and staff. Merit pay for the school as a unit would promote teamwork in a way that merit pay for individual teachers does not. Failure to meet the goals should be sufficient cause for a board of education to authorize an external group to study a particular school and prescribe remedies. In this way a school would not be allowed to drift along from year to year, ducking its responsibility for good science education.

Third, new developments and opportunities in science and mathematics education should be designed to improve the performance

of individual schools. For example, in curriculum development the purpose might be to design an entire rationalized school science program, rather than to provide better courses in the separate sciences. In teacher retraining, the focus should similarly be to upgrade the competency of the entire science faculty -- as a unit -- since it is as a unit that they would be held accountable. Counselors would receive instruction on why science and math is important for all students and on techniques for persuading students, especially girls and minorities, to continue taking these subjects.

This change in frame of reference might lead to, or benefit from, other changes in the structure of the system. For example, reducing the size of some schools might enable them to develop a stronger identity and allow faculty and students to get to know one another better. Increasing the stability of schools by reducing the number of involuntary transfers might enable principals and teachers to develop a stronger commitment to a particular school and allow them to work together long enough to become a true team. Thus, teachers could then begin the process of accepting responsibility for the competency of their colleagues.

Recommendation 2. Schools should discontinue offering instruction in subjects for which they do not have fully qualified teachers.

As long as state and local school authorities are willing, for whatever reason, to place unqualified teachers in science and mathematics classrooms, it will be difficult to create a demand for qualified teachers. If there is anything at all to the claim that teaching is a profession and that adequate teaching is not likely to come from a person who does not know the subject matter nor the techniques for teaching it, then schools show a lack of integrity -- if not outright hypocrisy -- when they condone the assignment of, say, a home economics teacher to a chemistry classroom in order to save a job.

Furthermore, there is the question of strategy. If we want the public, through its representatives, to search aggressively for ways to attract talented, well-prepared persons into science teaching, then we must impress upon them the true state of affairs. What better way than to notify them that unless qualified teachers can be found and employed in a designated field by a certain date, certain courses will be dropped! National and state statistics about "serious" or "critical" shortages will not promote a sense of urgency unless the community itself is aware that in its own schools some students are being assigned to learn science and math from unqualified teachers.

Should it happen that trigonometry and physics, for example, are not offered in certain schools in a state, all is not lost. The state itself should guarantee that all students needing such courses will get them, through correspondence courses, television, videotapes, computers, volunteer coaching by scientists, summer

courses, or by other means. This approach would motivate states to help affected schools to solve the problem of employing qualified teachers and put intense pressure on school authorities to change the structure of the school system. In any case, until the schools show they are ready to do without rather than employ underqualified teachers, "raising standards" will elude us, for otherwise a market for quality will not really exist.

Recommendation 3. Schools should employ science and mathematics teachers on a full-year basis.

Year-round employment for teachers would have the desirable consequence of increasing income and putting teachers on the same footing as other professionals, but that is not the main reason for advocating it here. I believe that full-year employment is a necessary condition for more effective teaching. Teachers need time -- time that is not now available during the school year in the face of 25 teaching hours per week and, for high school teachers, as many as 150 students per day. Teachers need time on salary to study, reflect, prepare new laboratory activities and demonstrations, compose better examinations, modify course content, and so forth. No matter how long the school year becomes, teachers need time at school without students.

Summer work, if it is to be effective in upgrading the school's ability to serve its students, must explicitly address departmental and school goals, be supervised by departmental heads and school principals, and be documented. Informal, undirected, independent study simply will not do. Approved academic study at a university or work experience in an industrial laboratory could on occasion be substituted, but only if it appeared to contribute to the growth of the teacher as a teacher. The overriding purpose of full-year employment must be to improve the school's effectiveness.

Because of the cost, it might be necessary to phase in year-round employment over the course of three to four years. If so, preference should be given to secondary rather than elementary school teachers, and among the latter, preference should be given to teachers in priority subjects, starting with science and mathematics. Science teachers desperately need time to repair and organize equipment, test new demonstrations and experiments, develop ways to attract science-shy students, become adroit in using computers, preview new films and books, coordinate the science curriculum with the school's mathematics program, stay current in their field, and much more. Math teachers have no laboratory to prepare for — though they probably should -- but they too need time to coordinate with the science department, preview, study, and above all develop activities and applications that will make math attractive to a larger spectrum of students.

If this change were to occur in parallel with a renewed national curriculum development effort, teachers, working as teams, could be expected to review the developing options, help design their system's syllabus, and undergo special training to be able to implement

whatever curriculum is eventually selected. This would also apply to the introduction of new learning technologies.

As we have seen, students in the United States spend substantially less time in school than do students in other countries, and several recent studies have recommended that a longer school day and year be instituted in this country. Nevertheless, until we have succeeded in using the time we now have more effectively and have carefully designed ways to use additional days, little will be gained by extending time spent in school. Eventually it will need to occur, but now teachers need to use the time when students are not in school to plan for the time when they are.

Teacher Preparation

In the current crisis much of the attention has focused on teachers — their compensation, competency, supply and demand. And so it should be, for the teacher is still the heart of the educational system. Many of the dozens of recommendations made in the various reports cited earlier make good sense, and if implemented would contribute to a better teaching corps. The recommendations do not, however, hit hard enough at the problem of training and retraining science and mathematics teachers. The following two recommendations suggest somewhat more radical approaches to the way this could be done.

Recommendation 4. With support from the federal government, the states should begin to exploit modern video and computer technologies for retraining today's teachers of science and mathematics and for building a permanent capacity for continuing teacher education.

Continuing education ought no longer be confined to brief workshops, to miscellaneous credits collected at a university, or to summer institutes attended once every five or ten years. Well-trained teachers of science need continuous study of their subject and the methods for teaching it. Teachers who are not well trained in science in the first place — most elementary school teachers and a growing fraction of junior and senior high school teachers — need much more in-service training than is now provided. More than one and a quarter million teachers currently need substantial updating in science and mathematics, and they will need it next year as well as the years after that. A one-time fix will not suffice.

On the other hand, technology — videotapes, computers, and interactive videodisks — makes possible dramatic new approaches to the formidable task of in-service teacher training, especially when used in conjunction with traditional methods. It is first necessary to produce good materials, but that would cost much less than sending all teachers back for standard classroom instruction. If business, other professions, and the military can use these means, why not teacher education? If anything, the stakes are higher in education, the benefit to the nation greater. And there is an additional

benefit from using modern learning technologies: teachers using these technologies themselves will gain a better understanding of how to incorporate them into their own teaching.

The purpose of this recommendation is not to eliminate teacher institutes or other traditional methods of in-service education, but rather to make such instruction more valuable by using modern information and communications technologies to carry the burden of day-in day-out continuing teacher education. A sophisticated system could make it possible for a school's science team to learn new content and master new techniques and equipment, to develop, indeed, as a team.

Recommendation 5. The licensing of teachers of science and mathematics should be based on passage of a subject-matter examination and satisfactory completion of an internship in a state-approved teaching school.

Restoring public respect for and confidence in the teaching profession will depend on many factors. Ultimately, none may count as much as visible evidence that teachers have been well prepared. The more we hear about how students of education come from the bottom of their class, the less likely are good students to go into teaching. That leads to still lower public esteem and reluctance of most of "the best" universities to take teacher training seriously enough to develop programs for future teachers with the same quality as their other programs.

It does not help that state credentialing standards usually amount to no more than an undemanding list of credits to be taken. We must find some way to break the decline -- the old ways simply are not working, because the old circumstances no longer exist. We cannot count on the "best and the brightest" women to flow into teaching now that they have other professional options. In the long run, this is healthy, for it may provoke us into thoughtful reforms of the teacher training enterprise.

Two suggestions are offered here, both of which are based on the belief that the public will only perceive teachers as better prepared when in fact they are better prepared. For most people, well-prepared teachers are persons who have demonstrated that they know their field and that they have the ability to teach it. As to the first, I propose that teachers be required to pass an external examination, and for the second, that they satisfactorily complete an internship at a recognized teaching school.

Examinations can be stultifying, but they need not be. Given a profession accorded such low esteem, with over 1000 teacher-producing institutions at every level of quality, but with most regarded as marginal, some measure is needed to ensure that every teaching candidate has a solid grasp of his or her field. Number of credit hours simply does not constitute evidence of knowledge, nor does an institution's self-proclamation about the quality and relevance of its courses for teachers. Outsiders must make that

assessment.

For science and mathematics, professional associations should help state officials, or the national board referred to below, set standards of knowledge which can be assessed by a two- or three-day examination. The science to be examined must reflect the context in which the teacher will need to know it, as differentiated from the science as it needs to be understood by a future researcher. Different testing organizations could then devise examinations to measure performance against national standards. Each state would have a choice of instruments and could set its own level for passage.

I believe that such a system would bring with it several positive side effects. One is that the undergraduate years would be programmed around the comprehension of one or more subjects, of which education per se would not be one. Another is that anyone at any time in life could move into an apprenticeship in teaching by demonstrating a satisfactory grasp of the subject they wish to teach. Teachers who are reassigned, and the officials who reassign them -- from biology to physics, for example -- would know what level of physics knowledge the teacher would have to reach during a specified grace period, since any permanent teaching assignment would be predicated on passage of a state-sanctioned examination in the subject area.

The other demand is for technical competence in teaching. Some universities are reasonably good at teaching the foundations of education: history, philosophy, sociology. But only a few are able to provide true apprenticeship training, even though they usually require observation and practice teaching in a nearby school. However, those schools are almost never designed to perform that task, so the usual procedure is for a few teachers at schools within commuting distance of the univerity to be designated as "master" teachers. They then provide a classroom, students, and some supervision. The university supervisors of practice teachers are usually not themselves current practitioners of precollege science teaching, which sets them apart from "masters" in other fields. On balance, the process we now use for apprenticeship training of future teachers is not sophisticated, not generally effective, and does not promote confidence in teachers by the general public. What the nation needs instead is a relatively small number -- perhaps a few hundred -- of actual elementary and secondary schools <u>dedicated to and licensed for</u> the technical training of teachers.

These teaching schools could specialize (by level and subject matter) and seek national status. Teacher training needs to break away from its localism, just as teaching hospitals have done. Admission could be set at a level high enough so that the school could concentrate on teaching teachers, secure in the knowledge that entering trainees at least knew their subject. Instruction would be systematic, intense, and demanding. A certificate of satisfactory completion would depend upon the recommendation of a designated faculty committee and be based on extensive observation of performance in predetermined situations. Unlike non-teacher

training, these schools would participate in research and development activities, keep up-to-date in all of the new materials and techniques, and provide in-service programs for other schools. The teachers (not the "interns" or "residents") in such institutions would themselves be highly selected and specially trained. Some teaching school might be connected to universities, but not as a special school for faculty children. Indeed, teaching schools need to be located in a variety of communities so that collectively they reflect the diversity of American life.

Establishing new ways for producing science and other teachers will take a decade or longer. It will take aggressive federal and state action, and perhaps the first step is to establish one or more research panels to present the range of possibilities and evaluate their strengths and weaknesses as well as their immediate and long-range costs. The point is to embark now on the search for new ways to produce the number and quality of teachers we need, for it is clear that our present system is failing.

The Federal Government

We have seen that the other nations examined in this book have been able to effect a sustained commitment to science education by means of a level of centralized leadership, planning, policy formulation, and investment by their governments far beyond what we are accustomed to in the United States. But the substantial involvement of the central government is, nevertheless, no less crucial in our own country. It is not sufficient by itself, but without it, national purposes are not likely to be served. Every report issued since 1980 that deals with science education has called for vigorous federal activity, even those that were primarily concerned with state and local action.[7]

What actions, then, should we expect at the federal level to help build and sustain a national commitment to the improvement of science education? First, the leadership of the President of the United States is indispensible. He should declare that attaining worldwide preeminence in science education is a national priority; he must translate that priority into a small number of clear, concrete, and achievable goals; and he must announce federal policies and programs that reach these goals in collaboration with the states. Beyond that there are at least four actions that would both reflect the national commitment and help sustain it.

Recommendation 6. An independent body should be established to define national standards in science and mathematics education.

Whether a separate commission or a part of some existing body, a group of knowledgeable representatives from the research and professional communities, teachers' and parents' associations, industry groups, and state boards of education should be established to provide a forum for setting baseline standards for science and mathematics curriculum content and scope, student performance, and

teacher preparation. Such a board, funded by Congress but operationally independent of the federal government, would be advisory to the public as well as to state and federal agencies.

If the nation has in fact accepted science education as a national priority, then state and local school systems can be expected to welcome such standards and to seek to exceed them in their own pursuit of excellence. Without an adequate definition of just what constitutes knowledge of science and mathematics, those who are responsible for educating our youth have nothing on which to set their sights. The establishment of ambitious — but realistic -- national standards would provide the states what they now lack: a frame of reference against which to measure their own science and mathematics standards for students and teachers.

Recommendation 7. The federal government should get back into the business of stimulating the development of innovative curricula and materials in science and mathematics, and it should stay there.

The justification is as it always was: the individual states and local school districts simply do not have the financial and professional resources to underwrite such projects. Furthermore, private enterprise cannot undertake responsibility for curriculum reform, for the investment is much too large and the risk too great. And, as we have seen, the commercial development of our textbooks, and the textbook-based curricula, has been characterized by convergence and caution rather than diversity and innovation. Only the federal government has the resources to see that our science education curriculum is fully developed and enriched, and that it is based on sound learning theory.

In some respects, a new curriculum effort can profitably emulate that of the 1960s. It should increase curricular options; it should involve both scientists and teachers; it should incorporate extensive field testing; and it should invite the involvement of private enterprise to publish and market the final products. But the effort should also be different in significant ways. In particular:

- Curriculum development must be an on-going process highly responsive to changes in science, technology, learning theory, and the needs and concerns of students, and of the society as a whole.

- In the elementary and secondary school years, greater emphasis must be put on science and technology literacy -- for all students -- and less on the specialized requirements of particular science and engineering careers.

- More emphasis should be put on the the applications of science, less on the theoretical structures of separate disciplines.

- The problem of student motivation and attitudes needs as much

attention as content. Especially in the early grades, helping students avoid feeling awed by or fearful of science can pay lifelong dividends.8

- Research should play a more prominent role, both as a basis for curriculum and materials development and as an outcome of the curriculum development process. In the absence of either theoretical principles or experimental verification, one program will continue to sound as good as any other. Plausibility, personal experience, and political considerations will continue to determine educational choices until rational and empirical grounds for making decisions are found and applied.

Recommendation 8. The federal government should undertake the design and installation of a nationwide education communications system.

At the time of Sputnik, when our scientific and technological preeminence seemed threatened, our nation's response was focused on and sustained by "the space race." Indeed, the goal became very concrete: be the first to get a man on the moon. People quickly came to accept the dual premise that if we were "to win," we would have to invest more than ever before in space-related research and development, and we would have to improve public education in science and mathematics. The research effort has been sustained and vastly productive. The educational effort flowered briefly, then faded.

Our new challenge may be thought of as "the productivity race," for in the minds of many, our ability to compete internationally depends upon getting better at applying science and technology, and that, in turn, depends upon strengthening science education throughout the nation. Unfortunately, that brings with it no external goal quite as concrete, understandable, and compelling as trying to reach the moon.

There is, however, one "internal" goal that is concrete and that might spark the nation's imagination: the technological modernization of our schools. A few more television programs for children will not do, nor will more personal computers in the schools. What is needed is a plan that is as breathtaking — and as achievable — as the national park system, the interstate highway system, the land-grant university system, the public libraries of Andrew Carnegie, and the development of rural electrification. Such a plan for modernizing our schools would involve satellite transmissions, dedicated frequencies, ground receivers, cable networks, video copiers and playback equipment, computers, and interactive videodisks — all designed expressly for the schools and available to each and every school in the nation. Some advantages of designing and installing the world's most complete and advanced education communications system are these:

- Simply designing such a delivery system would encourage, if not require, a penetrating examination of the content and

structure of science education (and other fields, too). The form and articulation of the various parts of the system would depend heavily on what material is to be transmitted and how it is to be used. The culling of existing learning materials, and the creation of new, would take on new urgency and new dimensions.

- The effective fitting of subject matter to delivery vehicle would necessitate extensive and continuing research and development on cognition and teaching as well as on the application of information, communications, and computer science to education. Thus we might finally begin to base our educational enterprise on systematic knowledge rather than on intuition, folklore, and habit.

- Fundamental changes would be possible in the way instruction is organized and teachers are utilized in the schools. Science and mathematics instruction could be improved by placing a relatively few outstanding and highly paid teachers in positions that allowed them to exploit fully their special talents. Material available on the education network could be monitored by assistants, apprentice teachers, and selected students. All students could have their class time and activities scheduled so that network resources would extend the reach of the best teachers. Opportunities for more productive self-directed learning would become available to any student.

- Such a system would make possible on-site, self-directed learning by teachers as well as students.

A large capital investment would be required to design and install such a system in a short time -- say five to ten years -- but in considering such costs, comparisons must be made to the cost of the alternatives: (a) sticking with what we already have and accepting the patchy, inadequate reforms we are likely to get; or (b) spending what it takes to get a cost-effective system that delivers first-rate science and mathematics education to all students and helps promote fundamental reforms in the entire system. This proposal is not offered as a technological quick-fix, but just the opposite -- as a long-term redesign of the educational structure that will fully and carefully exploit modern technological capabilities.

Recommendation 9. A panel of experts should be assembled to estimate the net cost to the nation for achieving excellence in science and mathematics education for all students, given various scenarios for how it could be accomplished, and to propose new ways and means for underwriting those costs.

Calls for, or resistance to, changes in the way we do business in education rarely have the benefit of economic analysis. Some plans for improving science education may be so compelling that they will be accepted regardless of cost, and others, much less expensive, may prove so unsuitable that they will be rejected out of hand.

Nevertheless, in the long run our chances for sustaining a major national commitment to the improvement of science education will be greatly enhanced by knowing how much it will cost.

A committee of experts -- in economics, organizational change, schooling, finance, business, technology -- should be assembled immediately to try to put various recommendations into financial perspective. The National Academy of Sciences and the National Academy of Education could very well accept this assignment. Collectively, the committee should be comprised of people who know cost accounting and the structure and governance of schooling in America and the nature of science and mathematics; should have access to all pertinent studies, both published and unpublished; and should have budget enough to hold hearings of its own. Its charges should include at least these four:

- The committee should estimate for the nation as a whole the cost and cost-effectiveness of proposed remedies, e.g., lengthening the school year, merit pay plans, differential staffing, curriculum development, teacher retraining via summer institutes, introducing new technologies, loan plans for enticing new recruits into science and mathematics teaching, increasing promotion and graduation science requirements, and providing resources for hands-on science learning.

- If the nation is to make sense out of projected costs, a scale is needed. The cost of specific recommendations must be computed in relation to total educational expenditures, to the GNP and other economic indicators, and to the cost of science education as it now stands. Without such measures, it is not really possible to decide whether any given proposition is too costly or a bargain compared to other options.

- The committee should determine the comparative impact of various approaches on local, state, and federal budgets, and on the quality of science education available to different categories of students. We need to know, for any given scenario, how the costs would be shared and the benefits distributed.

- The committee should analyze the educational costs that differentiate between operating and capital investment. Just to keep America's school system open and functioning is costly, given its more than two million employees, tens of thousands of school buildings, and 40 million students. To change that system requires an investment above and beyond its maintenance, especially if there has been a failure to build a "capital reserve." On the other hand, an investment in reform, while expensive in the short term, can, if prudently made, lead to long-term economics.

All of these factors must be sorted out so that we as a nation have

something sound to go on as we decide which remedies to support and at what levels.

AFTERWORD

One cannot help but worry about the tone of a work such as this, for in comparing our country to others, it is about as easy to become panic stricken as it is to remain smugly complacent. Neither response is justified.

The purpose of this volume is to help the United States chart its own course to better science education by pointing out what might be learned from other countries. The authors sought objectivity and balance. This last chapter, however, deliberately juxtaposed the educational strengths of China, the Germanies, Japan, and the Soviet Union against our shortcomings. But, of course, those countries have their own weaknesses in science education, and we our strengths. Let me end this essay, therefore, with a brief comment or two on that side of the ledger.

In the countries examined here, I believe that the form in which science learning takes place has two educationally debilitating features. One is substantial reliance on rote memorization. Understanding concepts, grasping the processes of scientific reasoning, hands-on learning, and the like too often give way in these countries to simple recall of "correct" answers. There may be too much rote learning in the United States, but it is not on the same scale. In this country our generally accepted goal -- if not always our practice -- is a balance between memory and understanding, knowledge and process.

The other dominant feature of science education in these countries is the examination. At certain key points in the system, students take examinations that determine once and for all which academic path they will be permitted to follow. Cumulative performance, as expressed in grades, the judgment of teachers, second and third chances, aptitude tests — all commonplace in America -- are much less a part of the educational equation in other countries. There is no substitute there for doing well on a given examination on a given day, and that day comes early.

Finally, there is the matter of innovation. The Soviet Union apart, the countries we studied here appear not to have been particularly inventive in the development of new methods and techniques in the teaching of science and mathematics to young people. Many of the most imaginative advances worldwide in the form and substance of science and mathematics teaching remain those that were generated in the United States by the curriculum projects of the 1960s.

Above all, however, the United States is still the land of opportunity -- educational opportunity and promise. That is our real commitment, our burden and our glory. What matters most at any time,

and what matters most right now, is not how we compare to other countries and to our own past, but how well we are doing in fulfilling our promise. Looking at others and looking backward, from time to time, can help us judge where we are headed and how we are moving. But it is our vision of the future, our future, the world's future, that counts most. If science and technology are to be a major part of that future -- and who would doubt it? -- then we must prepare all of our young people to meet the world of science and technology head on -- with understanding, style, and care, and with a vision of their own that is worthy of a country still committed to the promise of educational opportunity for all who would claim it.

NOTES

1. Since late 1980, a number of reports have been issued on the state of education in the United States. Of those that deal directly or indirectly with precollege science and mathematics, the following are of special interest:

Academy of Arts and Sciences, "Scientific Literacy," Daedalus, Spring 1983.

John I. Goodlad, A Place Called School (New York: McGraw-Hill, 1984).

National Science Foundation, Educating Americans for the Twenty-First Century (Washington, D.C., 1983).

National Science Foundation and the United States Department of Education, Science and Engineering for the 1980s and Beyond (Washington, D.C., 1980).

Task Force on Education for Economic Growth, Education Commission of the States, Action for Excellence (Denver: A. B. Hirschfeld, 1983).

The College Board, Academic Preparation for College: What Students Need to Know and Be Able to Do (New York, 1983).

The National Commission on Excellence in Education, A Nation at Risk: The Imperative for Educational Reform (Washington, D.C.: U.S. Government Printing Office, 1983).

The Twentieth Century Fund, Task Force on Federal Elementary and Secondary Education Policy, Making the Grade (New York, 1983).

2. Andrew Ahlgren and Herbert J. Walberg, "Changing Attitudes toward Science among Adolescents," Nature 245 (1973): 187-190.

3. Hope Aldrich, "Education Schools to Meet on Quality,"

Education Week, 12 October 1973, 5.

4. For the most comprehensive studies of the effects of the 1960s' science education initiatives, see:

Stanley L. Helgeson, Patricia E. Blasser, and Robert W. Howe, The Status of Precollege Science, Mathematics, and Social Science Education: 1955-1975, vol. 1, Science Education, vol. 2, Mathematics Education (Washington, D.C.: U.S. Government Printing Office, 1977). SE 78-73.

Robert E. Stake et al., Case Studies in Source Education, vol. 1, The Case Reports, vol. 2, Design, Overview and General Finding (Washington, D.C.: U.S. Government Printing Office, 1978). SE-78-74.

Iris R. Weiss, Report of the 1977 National Survey of Science, Mathematics and Social Studies Education (Washington, D.C.: U.S. Government Printing Office, 1977). SE 78-72.

For an overview of and reactions to the above studies, see:

Stanley L. Helgeson et al., The Status of Precollege Science, Mathematics, and Social Studies Educational Practices in U.S. Schools: An Overview and Summaries of Three Studies (Washington, D.C.: U.S. Government Printing Office, 1978). SE 78-71.

What Are the Needs in Precollege Science, Mathematics, and Social Science Education? Views from the Field (Washington, D.C.: U.S. Government Printing Office, 1980). SE 80-9.

5. Herbert J. Walberg, "Scientific Literacy and Economic Productivity in International Perspective," Daedalus, Spring 1983, 13-14.

6. Aldrich, "Education Schools." That a lot of testing goes on, that it is not systematic and does not produce comparable results, and that it is not useful for assessing students, teachers, and schools, is treated in two recent books:

H. J. Walberg, ed., Educational Environments and Effects: Evaluation, Policy, and Productivity (Berkeley: McCutchan, 1979).

H. J. Walberg, ed., Improving Educational Standards and Productivity: The Research Basis for Policy (Berkeley: McCutchan, 1982).

7. Task Force on Education for Economic Growth, Action for Excellence.

8. Gilbert S. Omenn, "Are Kids Afraid to Become Scientists?" Science 83, September 1983, 18.